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Quaternary Explosive Volcanism and Pyroclastic Deposits in East-Central Mexico: Implications for Future Hazards.

A New Orleans 1995 GSA Annual Meeting Field Trip Guide

by

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Introduction

This field guide describes a five-day trip to examine Late Pleistocene and Holocene pyroclastic deposits erupted from volcanoes in the east-central part of the Trans-Mexican Volcanic Belt. We emphazise the implications that these deposits bear upon this area, which is densely populated and has experienced an unprecedented economic and industrial growth during the past four decades. We will evaluate the risk that volcanism poses on life and property in this area and invite participants to discuss the problems of hazards mitigation in this socially complex environment.

This trip starts and ends at the Mexico-City airport (Fig 1). The first three days will be devoted to Popocatépetl (5452 m), a stratovolcano that became reactivated during the course of the last three years with increased seismic and fumarolic activity. The volcano finally started erupting in the early morning of December 21, 1994 with the nearly continuous pulsating emission of gases and ash. This situation poses enormous problems that still need to be resolved (see also the 1994 and 1995 issues of the Bulletin of the Global Volcanism Network).

During the first day we will ascend (o Tlamacaz (3950 m a.s.l.), the highest point that can be reached by car on the volcano and examine the most recent pyroclatic fall and flow deposits at this proximal location. During the second day we will circumnavigate the western, southern and eastern slopes and visit areas covered by gigantic Pleistocene debris avalanche deposits, as well as associated pumice-fall, and ash-flow deposits. During the morning of the third day young lahar deposits and Plinian pumice and ash-fall deposits from Popocatépetl that buried Prehispanic settlements near Santiago Xalitzintla, San Nicolás de 10S Ranchos, and San Buenaventura Nealtican on the eastern slope will be inspected. In the afternoon we will visit the archaeological site of Cholula, a major Prehispanic ceremonial center that was temporarily abandoned around 800 A. Il. because of a large major Plinian eruption from Popocatépetl. Then we will drive towards the NE and spend the night in Tlachichuca, located at the southeastern margin of the Serdán-Oriental intermontane basin.

The next two days will be devoted to volcanoes and their deposits located within, or at the margins of, the Serdán - Oriental basin. During the fourth day we will visit the western slopes of Pico de Orizaba stratovolcano (5700 m a.s.l.), the highest volcano on the North American Continent. There, a major Holocene block-and-ash fan on which several towns are located, will occupy our attention. Directly towards the North is Las Cumbres volcanic complex. On its western flank is the remarkable Quetzalapa Plinian pumice fall deposit, whose source is still uncertain. The age of this deposit which covers a minimum area of

2000 km2 is between 18000 and 25000 y. B.P. In the afternoon wc will visit the Las Derrumbadas rhyolite domes and focus our attention on their multiple debris avalanche deposits. We will also visit Tepexitl explosion crater and San Luis Atexcac maar crater, two of more than a dozen phreatomagmatic volcanic features in this region, before driving to Perote at the northern margin of the Serdán-Oriental basin. On the fifth day we will visit Laguna Alchichica explosion crater, as well as Cerro Pinto rhyolite dome. Then we will drive back to the SW, towards La Malinche (4503 m), the third major andesite-dacite stratovolcano of this field excursion. On the NE slope of La Malinche we will inspect Xalapaxco, an unusual tuff cone with multiple explosion craters, before visiting outcrops at the northern slopes of La Malinche. This volcano is generally believed to be extinct, but recent field work and dating of the youngest products indicates that it should rather be designated as a "*giant sleeper*". At the end of this day we will return to the Mexico-City International airport,

This text is a compilation of the volcanological work of researchers and students, at Instituto de Geofísica, UNAM with the collaboration of several foreign scientists. Most of the work descibed here represents the ongoing stages of major research projects and students' theses.

The Trans-Mexican Volcanic Belt: A brief review

All the volcanoes to be visited are located within the cast-central part of the Trans-Mexican Volcanic Belt (TMVB). The TMVB is an approximate E-W aligned structure which extends for more than 1000 km from the Pacific coast to the coast of the Gulf of Mexico (Fig. 2). The belt consists of a large number of Late Tertiary and Quarternary cinder cones, maars, domes, and stratovolcanoes, the chemical and mineralogical composition of which is largely characterized by a talc-alkaline series typical of the continental margin type. Although several hypotheses for the origin of the TMVB have been proposed (see reviews by Verma, 1985, 1987), most authors relate it to the subduction of the Cocos plate beneath the North American plate. Several key quetions related to this major volcanic belt remain unanswered. In comparison with other subduction related volcanic belts, the TMVB does not run parallel to a deep-sea trench, but is oriented obliquely forming an angle of ca. 150 with the Middle America Trench, Prior to the existence of the TMVB, a subduction zone oriented roughly NNW-SSE existed along the western margin of North America. We still do not know the exact sequence of events that lead to the present configuration with a subduction zone oriented WNW-ESE and the development of the TMVB. Another particularity of the TMVB is the abundance of scoria cones and other monogenetic volcanic structures which outnumber by several orders of magnitude the composite volcanoes. In addition several areas with alkaline volcanic rocks have been identified in recent decades and satisfactory answers regarding the origin of these anomalous lavas are still lacking. Many of of the major stratovolcanoes are aligned in a N-S direction, perpendicular to the general trend of the TMVB. The most prominent examples for this arc the volcanic chains Cofre de Perote - Pico de Orizaba, Ixtaccíhuatl - Popocatépetl, and Nevado de Colima - Vole/in de Colima. In each of these cases the older and more eroded volcano is located to the N, while the younger and more active volcano is located to the S at the front of the TMVB. These relationships also lack consistent explanation.

The fertility of the volcanic soil, favourable climatic conditions, and the availability of water in the intermontane lacustrine basins within the TM VB attracted Prehistoric nomadic people and fostered the rise of ancient civilizations. Urban development gave rise to major Prehispanic cities during the first 1300 years A. D., such as Teotihuacán, Cholula, Tenochtitlán (ancient Mexico-City) among others, leading to a significant population concentration in central Mexico. Conquest by the Spaniards temporarily stopped population growth, mostly because of epidemic diseases introduced from Europe and Africa. Today, almost 500 years later, central Mexico is the most densely populated area of the country with several cities with more than a million of inhabitants and Mexico-City being probably the largest city in the world with about 25 million people.

Unprecedented economic and demographic growth during the last decades have produced an enormous ecologic stress on the area with severe pollution of air and ground-water, vanishing lakes, deforestation and soil degradation. Because many of the volcanoes within the TMVB have long periods of repose between cataclysmic eruptions, their lower slopes and adjacent areas have been populated and economically developed, in many cases leading to potentially hazardous situations. Today most of the volcanological work carried out by geologists in Mexico is either related to the exploration for geothermal steam, or related to volcanic hazards studies.

Geologic History of Popocatépetl (5452 m) and its most recent activity

Although Popocatépetl *(smoking mountain* in Nahuatl, the language spoken by the Aztecs) ranges among the most famous volcanoes in the wor Id (its image occurs on seals, stamps, and bank notes, and is surrounded by mysticism and legends), little is known about its geology and no comprehensive geological maps exist. The volcano is at the south end of a 80 km-long volcanic chain that runs in a north-south direction and divides the Valley of Mexico in the west from the Valley of Puebla in the east. Popo is only 60 km southeast of

Mexico-City and 40 km west of the city of Puebla, which together contain more than 30 million inhabitants (Fig.3). The basement of the area consists of Cretaceus limestones, sandstones, and evaporates, (hat were folded during the Tertiary. intrusion of granodiorites produced contactmetamorphic aureoles in the host rock. These rocks crop out south of Popocatépetl in the States of Puebla and Morelos.

Today we know that the present cone is not the first huge volcanic edifice that evolved on this site as evidenced by the presence of at least three successive debris avalanche deposits that fan out towards the south. These deposits attest to the previous existence of large cones that were destroyed by gravitational collapse (Siebe et al., 1993, 1994). The last collapse probably occurred between 50000 and 20000 y. B. P. The oldest rocks found so far at Popocatépetl have not been dated yet, but they are stratigraphically younger than rocks from Ixtaccihuatl. This implies that Popocatépetl is definitely younger than its northern neighbour Ixtaccíhuatl, the oldest lavas of which were dated at 900000 y. by the K-Ar method (Nixon, 1989). Although Popocatépetl appears highly symmetrical, a deep amphitheater-shaped valley, Barranca de Nexpayantla cuts its northwest flank (Figs. 4 and 5). The headwall of this barranca, called Ventorrillo, forms a prominent topographic high and represents the remnants of an older destroyed cone.

At the top of the present cone is a large, 250 m deep crater with vertical walls (Fig. 6). The shape and morphology of this crater has not changed much since it has been recorded by photographs.

The present cone consists mostly of superimposed lavas and pyroclastic deposits of andesitic to dacitic composition. Common phenocrysts embedded in a microlithic to glassy matrix include plagioclase, hypersthene, augite, olivine, and less frequently biotite and hornblende. During the ice ages, Popocatépetl was heavily glaciated in a series of advances as evidenced by moraines and striae on bedrock lavas (White, 1954; 1981). Tens of scoria and cinder cones of more basic composition (basalts and andesites) occur to the west and east of the volcano.

The Late Pleistocene and Holocene (last 20000 y.) activity was characterized by at least 7 large Plinian eruptions that produced Plinian pumice-fall and ash-flow deposits. Fall deposits from these eruptions have been identified as far as Mexico City, Puebla, Ajusco volcano, and La Malinche volcano. Outcrops of ash-flow deposits produced by Plinian eruptions have been identified in the vicinity of many towns and small cities such as Atlixco, Cuautla, Oaxtepec, Ozumba, Atlautla, Amecameca, San Buenaventura Nealtican, and others in virtually every direction from the volcano. The last two of these types of eruptions ocurred within the period of human occupation ca. 2300 and 1100 y. B.P. with devastating effects as evidenced by archaeological remains buried by ash-fall beds and pottery shards incorporated by ash-flows units. Although the archaeological finds around the volcano are at this point fragmentary and mostly limited to the NE sector of the volcano (Seele, 1973, Uruñuela and Pluncket, pers. comm, 1995), we anticipate interesting and enlightening finds elsewhere in the near future. This is especially so, since we have been able to observe abundant archaeological material at many other outcrops to the W of the volcano,

The cataclysmic eruptions that so dramatically affected the early inhabitants of the area are not only reflected in myths and legends, but also in the geographic names of towns, barrancas and other topographic features. The names of many places start with either the Nahuatl prefix *"nex"* or the prefix *"xalli"*. *Nextli*, which means ash, is found in the names Nexapa (ash-flow) and Nexpayantla (where the ash brakes apart). *Xalli*, which means sand (sand-sized ash) occurs in Xallitzintla (ash-stream), and Xalliquehuac (place where the sand rises), among others. Because of the relatively long time intervals (1000 to 2000 y) between these major ash-producing eruptions the area has been repopulated due to the availability of water and agriculturally productive soil. A cataclysmic eruption of the same magnitude as those that ocurred at Popocatépetl on several prior occasions would have devastating effects of unprecedented dimensions in human history. Hence efficient disaster preparedness strategies must be developed by civil protection agencies.

Sensitive? Possible implication that local authorities wen't prepared for a disaster?)

Since the Spanish conquest in the early 16 th century, Popocatépetl has erupted several times but documentation of these events by witnesses varies in quality. All of these eruptions seem to have a common characteristic: Energy was released in a relatively gentle manner and eruptions produced mostly an ash plume with accompanying airfall deposit. This type of activity lasted for a few years. No major damage or casualties were reported.

In the early morning of December 21, 1995, Popocatépetl started to erupt again. Initial explosions were recorded by the seismic network that was installed around the volcano in previous months. This eruption ocurred with no major surprise, since increased fumarolic and seismic activity was recorded during the past two years and the media had reported about the increasing concern raised by the scientists. The seismic records indicate that the eruption must have started around 1:30 A.M. with vent clearing explosions that threw boulders as large as 40 cm in diameter out of the 250 m deep crater. These boulders were observed and collected by mountain climbers that reached the crater rim around 8:00 A.M. unaware of the eruption. Although about 25 mountain climbers spent the night at Tlamacaz, located only 4 km N of the volcano's crater, they neither heard the initial explosions nor felt any earthquake prior to the start of their ascent around 4:00 A.M. It was only just prior to reaching the crater rim that they heard the unusual sound like jet engines and noticed a dense ash plume rising in pulses from the crater floor. Although strong wind was blowing they were not able to see the crater floor at any moment.

During the first hours of the eruption, silt-sized ash reached several towns to the east and northeast of the volcano, including the city of Puebla, where a thin coating of ash deposited.

In the afternoon of that day the government decided to evacuate ca. 75000 people from towns in the State of Puebla to the east in what seems today to have been a somewhat premature decission. These people spent almost two weeks including Christmas and New Years in shelters provided by the local state government in schools that were available because of the Christmas vacation. The Governor of the State of Puebla took the chance to be kind to the citizens (mostly poor peasants) and distributed presents at Christmas to the evacuees. It is worth mentioning in this context that there has been friction between the authorities and the peasants over the use of water from the volcano. The rapidly growing city of Puebla has an increasing demand of water from further sources and seeks to supply its needs partly from the reserves at the eastern slopes of Ixtaccíhuatl and Popocatépetl. The peasants in that area need the water for irrigating their fields. The struggle for water even escalated to physical violence during the last two years, and we were able to sense the tension while doing fieldwork. It is to be hoped that after all these experiences these peasants will listen to the authorities in case of real danger and still follow instructions to evacuate their towns, when mandatory. We have our doubts about this and envisage potential for a tragic situation.

Sensitive (As seeming to judge the policies of other governments?)

Since the initial eruption, the volcano has been spewing ash almost constantly in a pulsating manner. The emission of ash has never ceased totally, but direct observations reveal strong fluctuations in the production rate. At times the volcano emits in short intervals (2-6 minutes) larger puffs (up to 5 in a row) that produce small cauliflower-shaped ash clouds that hardl y reach more than 1500 m above the crater rim. These clouds are deviated by the wind, which has been blowing almost exclusively to the NE, E, and SE (as of January 15, the time of this writing).

Although most of the towns to the east receive almost daily their share of very fine ash which everywhere produces extremely thin coatings, people seem to have gotten accustomed to it by now. They are in most cases convinced that the volcano does not represent a threat. This belief is in accordance with the erupions experienced during the last 500 years. Why worry so much, doesn 't Popocatépetl mean "smoking mountain"?

Sensitive (As implying that the people written about are backward?)

At the time of this writing the scientific committee advising the government essentially envisages two scenarios: a) The present eruption keeps going in the same way present with minor variations for an indefinite span of time and eventually ceases or b) at some point in the future it changes into a more explosive and violent style that produces ash-flows, lahars fed by rain and molten ice from the NW glacier, major Plinian pumice fall, etc. The present monitoring instrumentation seems to guarantee that a drastic change in eruptive style will be noticed at least some days or hours before an actual cataclysmic eruption occurs. An efficient monitoring system is relatively easy to install, if enough skilled scientists with modern equipment and a reasonable budget are provided. Coordination of civil protection agencies, health services, police, aviation safety authorities, military personnel, etc. in an area that includes the jurisdiction of three different federal states and numerous counties totalling more than a million inhabitants in the immediate surroundings of the volcano is a problem of a differnt dimension. In order to cope with this challenge much more skills, preparation, and organizational talent are needed, all of which science and modern technology obviously cannot supply.

Sensitive
(As implying that there's a lack of training & talent in Mexico as regards eruption preparedness?)

Popocatépetl's Late Pleistocene and Holocene pyroclastic activity

The modern cone of Popocatépetl is built on the remnants of previously existing cones that were destroyed by cataclysmic events of the Bezymianny or Mt. St. Helens type (Robin and Boudal, 1987; Siebe et al., 1993). The exact timing of the last event of this type is still unknown but it ocurred before 20000 y B.P. Since then, the present cone was constructed by alternating effusive and explosive activity. Most of the lava flows produced did not reach very far and are restricted to short distances (2-3 km) from the summit crater. Although the activity since the arrival of the Spanish conquerors seems to have been limited to episodic eruptions with outbursts of ash clouds, stratigraphic studies at the volcano indicate that many larger explosive eruptions ocurred during the last 20000 y. Some of these eruptions produced ash-flow deposits, Plinian pumice fall deposits, lahars and "blast" deposits which cover considerable areas and contain abundant charcoal. Carbon -14 dating of the deposits has been carried out by several workers (e.g. Heine and Heide-Weise, 1973; Lambert and Valastro, 1976; Robin, 1981; Cantagrel et al., 1984; Boudal and Robin, 1989; Siebe et al., in preparation). Unfortunately several inconsistencies regarding C- 14 results and lithological descriptions do not allow us to establish a definite eruptive history at this point. This is not the place to discuss the existing discrepancies in detail but we agree with Boudal and Robin (1989), that several cataclysmic eruptions with devastating effects ocurred during the last 20000 y. At this point, the eruptive history can be synthetized in the following way (see also Fig. 7):

Between 18000 and 14000 y. B.P. a major sequence of eruptions ocurred. These eruptions culminated in the emplacement of a Plinian fall deposit ("pómez con andesita" of Mooser, 1964; Ta-4 in Figs. 7 and 8) with a dispersal axis towards the NW. This deposit is one of the most distinctive units around the volcano and represents the most unique stratigraphic marker in the Valley of Mexico City. It consists of a heterolithologic fall breccia that includes juvenile dacitic orange pumice, grey microcrystalline granodiorite, pale green metamorphic siltstone, intense green contactmetamorphic hornfels, among other fragments from the local basement. The deposit has been identified unequivocally in such distant places from its source as downtown Mexico-City (70 km), the southern slopes of Ajusco volcano (70 km), north of Ixtaccíhuatl at Río Frío (30 km), and on the slopes of Xico tuff cone in the Chalco basin (40 km), (see also Figs. 1 and 3). At Xico tuff cone, an area of **shanty towns** in the outskirts of Mexico City, a well preserved section revealed a thickness of 25 cm with a maximum diameter of clasts of up to 5 cm; a roadcut located at the highway connecting Xochimilco with Oaxtepec, 35 km to the west of Popocatépetl displays a thickness of 50 cm for this unit with maximum dense lithic clast diameters of 10 cm! This eruption was most devastating and its possible effects in case of recurrence today certainly challenges our imagination.

Sensitive?

Between 10 000 and 8 000 y. B. P., as well as between 5 000 and 4 000 y. B.P. explosive eruptive periods which are well documented in the stratigraphic record, took place (Ta-3A and Ta -3B in Figs. 7 and 8). During these periods extensive ash-flows from column collapse or ash fountains were produced. These flows were channelized by the pre-existing topography and spread radially around the volcano, engulfing the vegetation and reaching considerable distances from the crater. They reached many places beyond the major break in slope at the base of the volcano, such as Amecameca, Xalitzintla, San Nicolás de 10S Ranchos, Ozumba, etc. These deposits are very similar and individual flow units not easy to correlate from place to place. They are normally massive, poorly graded with faint layering and contain variable amounts of yellowish-brown, subrounded pumice in a matrix of dark-grey, silty-sandy ash. These flows were very hot and produced abundant charcoal which is disseminated in the matrix. Where weathered these deposits have a light brown coloration and are semi-indurated.

Between 2000 and 2400 y. B.P. a major Plinian eruption ocurred, which caused the first known human catastrophe in the area. It produced a thick pumice fall with a dispersal axis towards the NE (Ta -2 in Figs.7, 8, and 13). The dacite pumice fall deposit is easy to recognize by its ocre-brown color and thickness. In addition, it contains minor amounts (less than 10 % by volume) of dark scoria and sparce pale-green metamorphic siltstone. The fall was preceded by a "blast", which produced thinn layers of cross-bedded, well-sorted silt and ash. The blast deposits are well preserved in the proximal areas right below the Plinian pumice. Accompanying ash-flow tuffs similar to Ta-3 were emplaced after the pumice fall. This eruption is significant because it destroyed Precolumbian settlements and agriculturally productive fields in the Xalitzintla valley towards the NE. Seele (1973) was the first to report archaeological findings buried by these deposits and Uruñuela and Pluncket (invited talk presented at the National University, January 1995) are carrying out more systematic excavations in the area. Preliminary results of these excavations indicate that the dwellers of the valley abandoned their settlements shortly before the eruption, but had not enough time to collect their belongings.

The Plinian fall deposit reaches thicknesses of more than 1 m in the Xalitzintla Valley between San Nicolás de los Ranchos and San Buenaventura Nealtican. The deposit has been recognized by us near Río Frio, north of Ixtaccíhuatl as well as on the southwestern slopes of La Malinche volcano. La Malinche is 60 km to the NE and 20 km beyond Cholula and the present city of Puebla. For this reason it seems very probable that the early inhabitants of the Xalitzintla valley were caught at some point by the eruption despite their initial effort to escape its lethal effects. Shortly after the peak of the Plinian eruption a lahar swept down the Xalitzintla valley, the drainage system of which was filled by the Plinian debris. We believe that future excavations at Cholula, one of the most importan Precolumbian ceremonial centers of Central Mexico, will yield interesting results regarding the early history of the entire area. Indeed, we would not be surprised if its importance as a religious center would be strongly linked to Popocatépetls eruptive activity and its major cataclismic eruptions that certainly also reached and maybe even destroyed Cholula.

If the above eruption was not enough, the stratigraphy reveals that the story repeated itself between 1200 and 1000 y. B.P. Another major Plinian eruption (Ta 6 in Figs. 7, 8 and 14), with initial “blast” and subsequent pumice fall and ash-flows occurred. This time the dispersal axis was towards the ENE, which essentially means that the same area was struck again. By that time the area devastated by the previous Plinian eruption was repopulated to a certain extent due to the availability of water for irrigation from the volcanoes. The stratigraphic sequence is almost identical to the sequence deposited during the prior eruption. The main difference consists lies in the coloration of the pumice, which for this event is pinkish-grey, instaed of ocre-brown. This makes it easy to distinguish the two deposits. The thickness of this horizon in the Xalitzintla valley is considerable and fluctuates between 40 and 80 cm near San Buenaventura Nealtican.

The Precolumbian history of Mexico is divided into several periods. Around 800 A.D. the Preclassic ends and gives way to the Classic. Although this subdivision is mostly based on differences in cultuaral development it seems to us that it cannot be a mere coincidence that it also falls within the timing of the Plinian eruption that produced the greyish-pink pumice. Not surprisingly, archaeologists who carried out excavations at Cholula during past decades report that Cholula was abandoned on several ocasions and (hat at least two fall deposits cover the ruins (e.g. Suárez and Martinez, 1993). In addition, they mention that Cholula ethymologically means "place of those who fled" or "water that falls at the place of those who fled". From what did they flee ? Do we need more hints ? We are convinced that archaeological excavations in the future at the lower slopes of Popocatépetl will reveal a wealth of information on the Precolumbian history of the area and the exact timing, eruptive mechanism and sequence of events that ocurred during the Plinian eruptions. With some luck the findings could be comparable in significance to those at Vesuvius in Italy or the site of Cerén in El Salvador.

Day 1: Late Pleistocene and Holocene deposits at the NW slopes of Popocatépetl

The first day of the trip will be devoted to the Late Pleistocene and Holocene pyroclastic deposits at the NW slopes of the volcano. For this purpose we will drive from the airport directly to Tlamacaz, the highest point at the volcano that can be reached by car. After discussing the geology of the summit cone, we will drive partly back toward Popo Park while stopping at a total of 10 outcrops. We will sytematically discuss all the deposits from the youngest to the oldest and gradually follow the changes in depositional environment from an upslope proximal facies to a medial facies at the base of the mountain. The direction in which Plinian fall deposits were dispersed will also be evaluated. The location of the stops and route arc shown in Figs. 1 and 4, and stratigraphic sections of the outcrops to be visited are shown in Fig.8.

Roadlog

Day 1: Mexico-City International Airport Popo Park

00.0 km. From the airport follow signs to Freeway No. 15(I to Puebla and enter the freeway exiting Mexico-City towards the east.

35.0 km Exit Freeway to the right and take highway No. 115 to the southeast in direction of Chalco and Amecameca.

63.0 km From the main square in Amecaameca continue on No. 1 I 5 southwards towards Cuautla.

65.5 km Take road (o the left to Paso de Cortés and Tlamacaz.

91.0 km AI Paso de Cortés take paved road towards the right to Tlamacaz (Stop 1-1).

96.0 km Tlamacaz mountaneering lodge. 30 m south of the lodge is a trench revealing proximal facies of Holocene Plinian deposits (outcrop 1-1, as shown in Fig. 8).

Stop 1-1. View of Popocatépetl from Tlamacaz mountaineering lodge

Popocatépetl´s present summit cone is built on the remnants of at least three previuosly existing edifices. One of these remnants is Nexpayantla palaeo-volcano, a notorious topographic feature rising to the NW of the present cone. The ages of Nexpayantla palaeo-volcano lavas range between 50 and 780 thousand years, as constrained by paleomagnetic measurements. The highest point of Nexpayantla palaeo-volcano is the peak called El Ventorrillo (ea. 5100 m). Its steep western wall, consisting of a sequence of strongly dipping andesitic lavas, can be observed in the right foreground of the snowcapped main cone of Popocatépetl (Fig. 5). El Ventorrillo represents the headwall of a major valley, Barranca de Nexpayantla. This deep and narrow barranca represents the largest drainage on the northwestern sector of the volcano. The valley becomes abruptly broader above the town of San Pedro Nexapa (13 km from the present crater), where a major break in slope occurs. (The word *nexapa* means ash-flow in Nahuatl, the language spoken by the Aztecs.) Here it broadens into an alluvial fan inclined towards the NW and W. At the far reaches of the fan the (own of Amecameca is located. Barranca Nexpayantla is certainly a major candidate for channelizing lahars and pyroclastic flows in future eruptions.

Popocatépetl´s modern cone also consists of andesitic and dacitic lava flows intercalated with pyroclastic deposits, Its crater has an elliptical shape with a major axis of 800 m and a minor axis of 600 m. This larger axis is oriented ENE - WSW. The highest crater rim and the summit (5452 m) are located in the WSW, and the lowest crater rim (5250) is in the ENE. The crater is bounded by steep walls that are more than 200 m high. At the bottom there used to be a turquoise-green lake (5000 m), filling a smaller interior crater produced by the explosive disintegration of a lava dome during the 1920-27 eruption (Fig.6). The present ash plume visible from Tlamacaz and elsewhere originates at the spot where the lake used to be within the crater. In 1992 fumarolic activity increased substantially in comparison to previous decades. This suggested a change in the sub-volcanic hydrothermal and magmatic systems. Airborne Correlation Spectrometer (COSPEC) measurements of S02 discharge during 1994 yielded values ranging between 680 and 3000 tons/day (see GVN Bulletins, 1994). This puts Popocatépetl among the five major producers of S02 presently active in the world, which is another cause for increased concern.

late Pleistocene-Holocene glaciers at Popocatepetl reached altitudes as low as 3900 m.a.s.l. leaving moraines that bounded the ice streams. These moraines are seen in the foreground of Figure 6, covered by ash and other pyroclastic air-fall deposits. The glaciers of Popocatepetl are considered to consist of two different ice bodies (Noroccidental and Ventorrillo) in terms of their distribution, although they could also be considered as one glacier since they share the same accumulation zone with a total glaciated area of 0.559 km2. Besides the glaciers, there are four permafrost fields with a total area of 0.239 km2. The amount of water contained on the flanks of the volcano is equivalent to .017 km3, an amount that should be taken into account for the evaluation of lahar risks. The melt water is current] y channeled by Barranca El Ventorrillo and Barranca Central, and both join together at an altitude of 3400 .a.s.l. to form a single stream that reaches the town of Santiago Xalitzintla at about 2500 m.a.s.l.

Roadlog (Day 1, continued)

96.0 km Take unpaved mad from Tlamacaz mountaneering lodge to the northeast to Cerro Tlamacaz radio station.

97.5 km Stop 1-2 at the northern slope of Cerro Tlamacaz. Right below the radio station is the outcrop shown in Fig. 8.

105.0 km Return to Tlamacaz lodge and drive back on the paved road to Paso de Cortés. At Paso de Cortés turn right on an unpaved road to the east towards Bucnavista and Xalitzintla. Stop 1-3 is the roadcut at the right side of the road 1 km east of Paso de Cortés (see stratigraphic section in Fig. 8).

109.0 km Continue on unpaved road towards Xalitzintla. Stop 1-4 is a roadcut on the left side of the road to the right of a young aa lava flow front (see stratigraphic section in Fig.8).

114.0 km Return to Paso de Cortés. This is the saddle which Cortés passed on his way to Tenochtitlán, the Aztec capital. The only monument dedicated to the Spanish conqueror in the entire country is here. Enjoy the view of both volcanoes, Ixtaccíhuatl and

Popocatépetl. Walk 200 m downslope to the NW along a path in a small gully that runs in the same direction. Stop 1-5 is an outcrop in this gully (see stratigraphic section in Fig. 8).

114.5 km Continue on the paved road towards Nexapa to the W. After 500 m on the left side next to an abandoned building is a roadcut. This is Stop 1-6 (see stratigraphic section in Fig. 8).

115.5 km Continue on the paved road towards Nexapa. After 1 km on the left side in a narrow left curve is a roadcut. This is Stop 1-7 (see stratigraphic section in Fig. 8).

117.5 km Continue on the paved road towards Nexapa. After 2 km on the right side, 30 m behind a narrow left curve is a 30 m long outcrop produced by a construction caterpillar. This is Stop I-8 (see stratigraphic section in Fig. 8).

128.5 km Continue for another 11 km on the road to Nexapa. Shortly after the major break in slope at the margin of the forest on the left side of the road is a 100 m long roadcut. This is Stop 1-9 (see stratigraphic section in Fig. 8).

138.5 km Continue driving through Nexapa and reach the junction of highway No. 115.

150.5 km Turn left towards Cuautla, pass Popo Park and turn left at the entrance of Ozumba where you abandon highway 115. Drive to the main square of Ozumba and make a left turn taking the paved road towards Atlautla. 200 m after leaving Ozumba on the road to Atlautla is Stop I-10, a roadcut in a topographic depression on the right side of the highway (see stratigraphic section in Fig. 8).

157.5 km Return to Popo Park. Behind "Restaurante Español" on the right side of the road is the entrance to Hotel "Los Volcanes", which cannot be seen directly from the highway.

Day 2: Recurrent cone collapse and gigantic debris avalanche deposits at Popocatépetl

Gravitational cone collapse of domes and strato-volcanoes and the subsequent emplacement of debris avalanche deposits represent one of the largest hazards posed by volcanoes to nearby populations. Preliminary field work at the southern and eastern slopes of the volcano and analysis of Landsat TM images (Fig. 3), both indicate that Popocatépetl volcano collapsed at least three times towards the south during the Late Quaternary producing a typical hummocky topography. A total of four different debris avalanche deposits have been recognized in the area, but it is not entirely clear yet if some were derived fom Ixtaccíhuatl prior to the existance of Popocatépetl (Fig. 9). To the south several outcrops at proximal as well as distal areas from the present cone show three debris avalanche deposits separated by volcaniclastic deposits and a well developed soil horizon. The three deposits are very similar in extent, lithology, and internal structure showing characteristic jigsaw-fit structure. A fourth deposit was identified at the eastern slopes of the volcano, to the north of the town of Atlixco. At this stage of our study we believe that this deposit originated from Ixtaccíhuatl, a volcano believed to be essentially extinct (Nixon, 1989).

The existence of a large debris avalanche deposit at Popocatépetl was first recognized by Robin and Boudal (1987). According to these investigators the deposit has a volume of 28 to 30 km^3, covers a surface of 300 km2, has a runout distance of 30 km, and is probably less than 50000 years old. Our preliminary studies indicate that the avalanches traveled at least as far as Huehuetlán El Chico, which is more than 70 km south of the present cone and therefore much farther than reported by Robin and Boudal (Fig. 9). Although our study is not completed yet, we can anticipate major differences with the results presented by Robin and Boudal. The recognition of at least four different debris avalanches is compatible with studies at other Mexican volcanoes (e.g. Colima, Pico de Orizaba, Las Derrumbadas) which also collapsed several times during their recent geologic evolution. This implies that repetitive cone collapse of a volcano should not be envisaged as an isolated phenomenon but appears to be more common than previously believed. The decade long fumarolic activity that preceded the present eruption certainly weakened the stability of Popocatépetl and possible collapse should be taken into consideration in the future. This is especially so, since Popocatépetl is a large and mature volcano and volcanoes do normally not grow much higher in altitude.

During the second day we will drive from Popo Park to Cholula and circle the volcano along its western, southern and eastern slopes (Fig. 10). All outcrops to be visited will focus on the debris avalanches and associated deposits. An idealized stratigraphical column is shown in Fig. 11. Individual stratigraphical columns of outcrops 2-1 to 2-9 are shown in Fig. 12.

Popo´s debris avalanche deposits (DAD in Fig. 12) are noteworthy because of their gigantic extent and large size of proximal hummocks. In this respect they are similar to the deposits associated with the last Bezymianny type event. After initial slope failure and cone collapse, sudden depressurization of the hydrothermal system lead to an enormous explosion ("blast", BD in Fig. 12). This explosion produced a series of turbulent diluted flows that formed deposits very similar to "surge" deposits normally found in the proximal facies of phreatomagmatic explosion craters. The "blast" deposits at Popo arc remarkable because of their thickness, long distance from the crater at which they were deposited, and maximum size of clasts encountered (up to several m in diameter more than 10 km from the source !). The deposits consist mostly of sand, gravel, and boulders, show cross stratification, and frequently have erosive lower contacts.

After deposition of the "blast" the eruption developed into a Plinian-type eruption, directly tapping the magma reservoir. A Plinian pumice-fall (PFD in Fig. 12), several meters thick, followed by extensive ash-flows (AFD in Fig. 12) were deposited. This Plinian pumice-deposit is the thickest of its kind at Popocatépetl and consists of a whitish-brown pumice rich in biotite. Its dispersion axis is not exactly known, but the most impressive outcrops occur on the southern slopes.

An ash-flow lying directly on top of the "blast" deposit was dáted by the C-14 method and yielded an age of 22875 +55/-50 y. B.P. Whether this is the. exact date of this eruption is not entirely certain yet and needs to be further constrained. But it is clear that no Bezymianny-type event ocurred since then.

Roadlog

Day 2: Podo Park - Cholula

00.0 km Take highway No, 115 to Cuautla and drive to outcrop 1-10 at the exit of Ozumba.

14.0 km Continue to Atlautla and take the paved road to Ecatzingo. 1 km before arriving at the maln square of Ecatzingo is a 20 m long roadcut on the right side of the road. This is Stop 2-1 , (see stratigraphic section in Fig. 12).

18.0 km Enter Ecatzingo and take the unpaved road to Ocoxaltepec. 400 m before Ocoxaltepec is a roadcut on the left side of the road. This is Stop 2-2, the most impressive outcrop showing the "blast" deposit. (see stratigraphic section in Fig, 12).

21.0 km 400 m after Ocoxaltepec on the road to Tetela de] Volcán is a roadcut in Barranca Xoxquezalco on the left side of the road. This is Stop 2-3, which shows the youngest debris avalanche deposit and associated Plinian deposits on top (see stratigraphic section in Fig. 12).

34.0 km Continue on the unpaved road for 8 km to Tetela del Volcán and enjoy the view of the large hummocks. In Tetela take the paved road towards Hueyapan. After 5 km is Stop 2-4 at a large quarry on the right side of the road. The quarry displays the internal structure of a hummock with shear zones and jigzaw-fit structures.

41.0 km Continue on the paved road to Hueyapan. After 5 km reach the entrance of Hueyapan and turn right on the road to Amayucan. After 2 km is Stop 2-5 at a large quarry on the right side of the road. The quarry shows the debris avalanche deposit, Plinian pumice fall, and ash-flow deposits.

43.0 km Continue for another 2 km on the road to Amayucan. Stop 2-6 is a 100 m long roadcut on the right side of the road showing two debris avalanche deposits separated by a reworked horizon converted into a soil.

49.0 km Continue for another 6 km on the road to Amayucan. Before reaching Tlacotepec is Stop 2-7, a quarry on the right side of the road shows the youngest debris avalanche deposit with hydrothermally altered blocks. From here a good view can be obtained over the plains covered by the debris avalanche deposits to the south of Popo. This area represents the medial depositional facies of the avalanche and a major break in slope. Hummocks are smaller and emerge from the inclined plain. From here on, the debris avalanche deposits are mostly covered by fluviatile and laharic deposits. At some distance towards the SE three major steep massive hills emerge from the plain. They consist of Tertiary granodiorite around which the avalanches flowed on their way further to the south (see also Fig. 3).

58.0 km Continue on the same road, drive through the towns of Tlacotepec, Zacualpan de Amilpas, Ternoac and reach the junction with highway No. 160 in Amayucan. Here turn left on highway No. 160 towards Izúcar de Matamoros. After three km park the carat the side of the road behind a bridge over the 20 m deep Barranca Tequexquia. This barranca is dry during most of the year and displays outcrops showing three superimposed debris avalanche deposits. On top is a series of fluviatile and laharic deposits. This is Stop 2-8.

103.0 km Continue on highway No. 160 towards Izúcar de Matamoros. After Puente Tepexco the road winds up a ridge of Cretaceus limestone that was partly covered by the debris avalanche deposits. It is dangerous to stop here but roadcuts show the contact between the limestone and the. debris avalanche deposits. Shortly before reaching Izúcar large quarries were gypsum and anhydrite are mined can be seen to the left of the road. These evaporite series are of regional extent and certainly atso occur below Popo. This might have implications for Popos high S02 discharge from Popo.

145.0 km In Izúcar de Matamoros turn left on highway No. 190 towards Atlixco.

168.0 km In Atlixco continue on highway No. 190 to Atzompa. About 6 km behind Atlixco the road climbs up a ridge. On the left side is a 200 m long roadcut displaying a debris avalanche deposit covered by a series of ash flows. This debris avalanche deposit is the oldest recognized so far around Popocatépetl. Apparently it originated from Ixtaccíhuatl. Within the yellowish-brown ash-flow series is a whitish Plinian pumice horizon, which correlates with the Plinian pumice deposit on the. south flank of Popo. Continue to Atzompa, Tonantzintla, and reach the hotel "Calli Quetzalcóatl" at the main square of Cholula. Cholula is not only important for its Prehispanic ruins, but also reknown for its many churches, especially the fortress-monastery built in the 16th century.

Day 3: Prehistoric settlements at Popocatépetl buried by Plinian Pumice fall, ash-flow deposits and lahars

This day is dedicated to seeing effects of Popocatépetl's last major eruptive activity on Prehispanic settlements in the valley of Xalitzintla (Fig. 13).

Sensitive ?

The Xalitzintla valley has been an attractive site for habitation because of the abundance of water and volcanic soils. The catchment area above Xalitzintla drains both the northeast flank of Popocatepetl and the southwest flank of Iztaccihuatl, providing a year-round water supply. Competition four this resource is fierce, even at present, as the city of Puebla is trying to appropriate the water to meet the city's needs. Confrontations between the villagers and Puebla escalated to the point where armed intervention was necessary to calm both parties. Nevertheless, the city of Puebla continues efforts to tap the water supply and has an ongoing program of geophysical exploration and drilling in the Xalitzintla valley.

At the same time that the numerous and well - developed barrancas channel water from the volcanoes' upper reaches, they have provided conduits for pyroclastic flows, debris avalanches, and lahars. Associated with these flows were deposits from Plinian eruptions: ash falls, pumice deposits, and blasts and surges. During the field trip we will see the evidence that major volcanic eruptions occuring between 2300 and 1000 years B.P. had a major impact on the entire area, and in particular on the Xalitzintla valley.

At least two major Plinian pumice falls, lahar flows, and one blast deposit, as well as accompanying pyroclastic ash flows directly affected the area to such an extent that probaby there were few survivors of the eruptions and most of the vegetation was destroyed. Although at this time archaeological evidence is still scarce, we anticipate major discoveries in the near future. So far archaeologists of the Universitad de Las Americas have discovered furrowed corn fields and pottery directly below the lower Plinian pumice fall. In addition, we have found pottery sherds within pyroclastic flows both on top of this lower pumice and also directly below the upper pumice, which we dated by C-14 at 1100 years BP. This age is coincident with the abandonment of Cholula around 800 A. D., one of the largest Prehispanic cities and an important ceremonial center. Although the exact reason for the depopulation of the city is not known at this point, we strongly believe that it is ultimately the result of this very destructive eruption,

Sensitive? (As telling a local population and/or government what to do?)

Despite this experience, the entire area was repopulated and settlements were reoccupied. Today hundreds of thousands of people live and work in the areas that were affected by this eruption. Intensive studies and continuous monitoring of Popocatepetl should therefore be mandatory.

This day we will visit outcrops of young volcanic products located between Cholula and Santiago Xalitzintla along the road to Paso de Cortez. For convenience we will drive on the shortest route to Santiago Xalitzintla and then gradual l y return to Cholula making several stops (Figs. 13 and 14). Back in Cholula we will visit the archaeological site and at the end of the afternoon drive to Tlachichuca at the western slopes of Pico de Orizaba.

Roadlog

Day 3: Cholula - Xalitzintla - Cholula - Tlachichuca

00.0 km Departure at the main square of Cholula towards the SE.

*

27.0 km Exit Cholula and take the road (o Paso de Cortez. The pavement ends shortly before San Buenaventura Nealtican, 18 km ESE of Cholula. Continue on this road, passing through San Nicolas de Los Ranchos and reach Santiago Xalitzintla. Stop 3-1 will be at at the main square in Xalitzintla. Here we will see the general topographic configuration of the Xalitzintla valley and the reasons for this town to he a prime candidate for destruction by volcaniclastic flows. The town is located on the margins of Barranca Nexapa , whose tributaries drain the entire northeast quadrant of Popocatepetl (including the glaciers) as well as the southeast quadrant of Iztaccihuatl, a total area of about 150 km2. The abundance of subrounded dark andesite blocks scattered throughout the village and used as building material for fences and structures is striking. The source of these blocks arc laharic deposits.

30.4 km Wc continue for 3.4 km through the town of San Nicolas dc los Ranchos and stop before the bridge across the Barranca Nexapa, next to a school and at the junction leading to San Pedro Yancuitlalpan. This is Stop 3-2. Exposed in the hillside are two lahar deposits, each greater than 3 m thick. The lahars arc matrix supported and cemented; the matrix is sandy-silty. Clasts are heterolithologic, but there is a preponderance of angular to subrounded dark andesite porphyry with a maximum diameter of 30 cm.

33.0 ktn To reach our next stop, the collapsed bridge below San Nicolas de los Ranchos, we need to continue towards San Buenaventura Nealtican for 1.6 km, then turn right and drive I km towards the SW. Stop 1-3 is on the east and west ends of the bridge. Take the footpath across the bridge and stop at the outcrop exposed SO m further on the left hand side. Here we can see the medial facies of the lahar sequence; three separate lahar flows are exposed (see stratigraphic section in Fig,. 13). The lahars arc similar to those of the previous stop, although clasts tend to be larger. Crossing back over the bridge, on our left in the hillside is exposed a section of the Plinian deposits with 2 lahar deposits intercalated (Fig. 13). At the bottom of the section is the upper 3 m of a yellow ash-flow tuff containing charcoal and pottery sherds. Overlying the ash flow is 70 cm of ochre pumice representing the first Plinian event. The upper 2 cm of the pumice deposit is an incipient soil where we found charcoal and pottery sherds. Above the pumice arc two lahar deposits, each about 60 cm thick. This is the marginal facies of the lahar where it thins out against topographic highs.. On top of the lahars is a second Plinian pumice Ian sequence, about 1 m thick. The sequence consists mainly of three pink and white pumice layers with two thin interbedded dark gray ash layers.

37.0 km Continue down the road from San Nicolas dc los Ranchos to San Buenaventura Nealticán for 4 km and turn right into a pumice quarry. This pumice is used to manufacture building blocks for houses and businesses; several of these operations were seen along the road from Cholula. Exposed in the walls of the quarry is an excellent section of Popocatepetl's Plinian eruptions (Fig. 14). The bottom of (he exposed section is a brown ash-flow tuff, partly altered (Ta-3); the tuff contains abundant charcoal. On top of the tuff layer can be recognized furrows of corn fields; pottery sherds and entire pots have also been found here. Above the ash flow deposit is a thick (103 cm) ocre Plinian pumice fall deposit (Ta-2) with maximum clast size of 6 cm. Overlying the pumice deposit are two thin gray and ocre sand and silt deposits representing blast and surge deposits that preceded the next overlying pumice layer (Ta 6). The upper Plinian pumice deposit consists of 6 cm of pink pumice overlain by a 2 cm thick layer of gray ash, 18 cm of pink pumice, a thin dark ash layer, 5 cm of pink pumice, another thin gray ash layer, and 45 cm of white pumice with a maximum clast size of 6 cm. The top of the section is a 50 cm thick layer of reworked soil and pumice with a soil developed at the top. This is essentially the same section we saw at Stop 3-3 but without the lahar deposit.

41.0 km Following the dirt road towards San Buebaventura Nealtican, for 3 km further there is a deviation to the right which leads us to a large quarry where the people are mining the Nealtican lavas. The lava flow was erupted from a fissure on the northeast flank of Popocatepetl at an elevation of about 2400 m, and covers an area of about 40 km2. The flow front here is 20 m thick. At this site we can scc the relationship between the lava flow and the overlying pumice sequence. These massive to vesicular lavas are olivine and plagioclase basaltic andesites with an aphanitic groundmass. They are characterized by the large amount and variety of xenoliths, including granulites and ultramafic rocks. Based on stratigraphic criteria, we know that this flow is older than the ochre pumice fall deposit (2000 years BP) and may be younger than the yellow ash-flow tuff whose surface contains abundant evidence of human occupation. The Nealtican lava shows that the hazards to the population of the Xalitzintla valley is not just from the air, but also along the ground. While people are seldom hurt or killed by lava flows, the destruction to property and elimination of agricultural lands is real enough and poses an economic risk, particularly to an agrarian population.

62.0 km Return to the main road connecting San Nicolás de los Ranchos with San Buenaventura Nealticán and turn right. Continue back to Cholula and stop at the archaeological site. Guidebooks explaining the history and other aspects of the site are sold here at souvenir shops.

179.0 km Take the Freeway to Puebla (10 km). In Puebla follow the signs to Freeway No. 150 to Veracruz which exits Puebla in the NE of the city. Take the freeway to the east in the direction of Veracruz. After 47 km exit the freeway near Acatzingo and take highway No. 140 in the direction of Perote. After 28 km reach San Salvador El Seco and continue on highway 140 for another 8 km in direction of Zacatepec until you reach a junction. Turn right towards the cast in direction of Tlachichuca. After 24 km reach Tlachichuca and ask for the mountaineering hostel of Sr. Francisco Reyes. The hostel is near the main square and is located in a former soap factory.

Day 4: Late Pleistocene and Holocene explosive volcanism in the Serdán-Oriental basin I.

During this day several volcanic structures and their deposits located in the interior and at the eastern margin of the Serdán-Oriental intermontane basin will be visited. We will first visit a major block-and-ash deposit at the western foot of Pico de Orizaba, then inspect Plinian pumice fall deposits at the Las Cumbres complex. The second half of the day will be devoted to the rhyolite monogenetic Las Derrumbadas domes and rhyolite explosion craters Tepexitl and San Luis Atexcac. At the end of the day we will drive to Perote at the northern margin of the Serdán-Oriental basin (see Figs. 15, 16, and 17).

The Serdán-Oriental intermontane basin

The Set-dAn-Oriental intermontane lacustrine basin represents the easternmost part of the Mexican Altiplano. The basin today has interior drainage and its lowest areas are occupied by the Totolcingo and El Salado saltpans, attesting to the former existence of extensive lakes during pluvial periods. The basin has an area of about 15,000 km2 and an altitude of approximately 2,300 m a.s.l. It is surrounded by Miocene to Quaternary strato-volcanoes and calderas of mainly andesitic to dacitic composition (Weyl, 1977; Robin and Cantagrel, 1982; Ferriz and Mahood, 1984). The most prominent among them are La Malinche stratovolcano in the SW, Los Humeros Caldera in the N, and the Cofre de Perote-Las Cumbres-Pico de Orizaba-Sierra Negra volcanic chain that separates the basin in the E from the plains of the Gulf of Mexico. Although the basin is surrounded by long-lived composite volcanic edifices, its interior is characterized by a large variety of monogenetic volcanic structures such as rhyolite domes, tuff cones, tuff rings, lava flows, and scoria cones. The Las Derrumbadas, Cerro Pinto, and Cerro Pizarro rhyolite domes are the most prominent volcanic structures in the interior of the basin and the more subdued phreatomagmatic maar craters rank among the most beautiful in the world.

The entire area is underlain by Cretaceus limestones which were intensly folded during the Laramide orogeny. During the Tertiary the limestones were intruded by granodiorites and monzonites which produced contact metamorphic aureoles and skarn-mineralization in the host rocks. Terrigeneous and lacustrine sediments were deposited after uplift during the Tertiary and Quaternary and are intercalated with the products of volcanic activity, which probably commenced in the Miocene/Pliocene (Negendank et al., 1985).

Holocene block-and-ash fan at Pico de Orizaba volcano, a *"giant sleeper"*

Pico de Orizaba or Citlaltépetl (19°04' N / 97°1S' W / 5700 m a.s.l.), located in the eastern part of the Transmexican Volcanic Belt (TMVB), is the highest volcano on the North American Continent. The ice-capped summit cone ranks as one of the most perfectly symmetrical volcanoes in the world. It rises 4500 rn above the Gulf of Mexico coastal plains situated to the east, and 3000 m above the Mexican Altiplano to the west.

The summit crater is a relatively small oval with a major NW-SE axis approximately 400 m long. The 300-m deep crater pit is surrounded by nearly vertical walls, exposing an alternation of lavas and pyroclastic units.

The present cone is composed mostly of andesite and dacite lavas. It was built on top of older volcanic structures that consist of a roughly N-S aligned, deeply-eroded volcanic chain formed by extinct constructs of the Cofre de Perote (42S2 m) stratovolcano 50 km to the north, Cerro de las Cumbres (3940 m) complex 10 km to the north, and Sierra Negra (4580 m) 5 km to the south (Fig. 16.). It is generally claimed that volcanic activity within the TMVB has migrated toward the south (e.g., Cantagrel and Robin, 1979; Luhr and Carmichael, 1985). However, this model does not apply to Pico de Orizaba because the highly eroded Sierra Negra, which is clearly older than Pico de Orizaba, is located south of the active volcano (Dannenberg, 1907). According to Cantagrel and Robin (1979), the Sierra Negra - Cofre de Perote chain supposedly lies on a zone of normal extensional faults which are also oriented in a N-S direction and which separate the Altiplano highlands from the plains of the Gulf of Mexico. This hypothesis has not been proven yet. In fact, most faults in the area run either in a NW-SE or NE-SW direction, suggesting that the volcanic centers fermi ng the N-S oriented chain are located at zones of weakness where these faults intersect.

During the 19th and early 20th century the majestic appearance of this mountain attracted many travelers who collected the first scientific data including barometric measurements and observations of fumarolic activity at the summit area (e.g., Heller, 1853/1857; Pieschel, 1856; Sausurre, 1862; Müller, 1864; Plowes el al., 1877; Ratzel, 1878; Heilprin, 1890; Angermann, 1904; Waitz, 1910; 1915; Garcia, 1922; Friedländer, 1930/31). Given these early studies, it is surprising that this volcano has not been investigated more thoroughly in recent decades.

Although the volcano has shown only fumarolic activity for the last 300 years (Heller, 1857; Angermann, 1904), studies by Robin and Cantagrel (1982) and Robin et al. (1983)

demonstrate that it had several important eruptions during the late Pleistocene and Holocene. It is therefore justifiable to call this volcano a *"giant sleeper"*.

Torquemada (1615) reports that the volcano became active in 1545 for more than twenty years and that the Indians until then believed the volcano to be extinct. Mühlenpfordt (1844) also mentions that the last major historic eruption took place between 1545 and 1565; whereas Waitz (1915) cites another eruption that occurred in 1687, Recent studies revealed the existence of debris-avalanche deposits derived from the partial gravitational collapse of the former cone (Sheridan et al., 1990; Høskuldsson, 1990; Høskuldsson et al., 1990; Carrasco et al., 1993).

Based on preliminary fieldwork, Høskuldsson et al., (1990) claimed to have discovered four different debris-avalanche deposits at Pico de Orizaba. Three of them are of the Bezymianni-type and traveled toward the east, whereas the fourth is considered by these authors to have originated from a landslide that traveled 12 km west from the summit of the volcano, leaving a pronounced horseshoe-shaped scar on the upper part of the cone. The deposit supposed] y covers an area of 42 km^2, has a volume of 1.5 km^3, was emplaced without accompanying magmatic activity, and is older than 38000 y. B.P. (Høskuldsson, 1990; Høskuldsson et al., 1990) .

Results of more recent studies were presented in Siebe et al., (1993). In that report conclusions from investigations of the "landslide-like looking" deposit were presented and an alternative explanation for its origin was given, namely that the deposits under discussion represent a block-and-ash fan. Accordingly, this deposit is a composite accumulation of many pyroclastic flows, flood deposits, and lahars that were channeled through a glacial cirque and connecting U-shaped valleys toward the base of the volcano where they were deposited.

The block-and-ash fan extends more than 14 km westward from the summit of Pico de Orizaba volcano in the eastern part of the Trans-Mexican Volcanic Belt (Figs. 17, 18, and 19). Radiocarbon dating of charcoal within the fan deposits yielded Holocene ages that range between 4040 ± 80 and 4660 ± 100 y B.P. (Fig. 20). Stratigraphical, sedimentological, geochemical, and scanning electron microscope studies indicate that this fan originated within a relatively short time-span by multiple volcanic explosions at the summit crater. This activity produced a series of hornblende - andesite pyroclastic flows (mainly block-and-ash, flows) and lahars which were channelized by a glacial cirque and connecting U-shaped valleys as they descended toward the base of the volcano. Repeated deposition of pyroclastic flows formed a tongue-shaped fan of volcaniclastic deposits that can be easily traced on satellite images (Fig. 18). The area of the present fan should be considered a zone of high risk in case of renewed activity because it is very likely that future flows will use the same pathways. A recurrence of a similar eruption today would pose severe hazards to the population of more than 50,000 people who live in a potentially dangerous zone (Figs. 21 and 22). A detailed reconstruction of the sequence of events that led to the formation of the block-and-ash fan will be discussed. Special attention will be given to the effects of an ice-cap and the role of pre-existing glacial morphology on the distribution of products from such an eruption.

Las Cumbres Volcanic Complex and tbe Quetzalapa pumice

The name of Las Cumbres Volcanic Complex (LCVC) is used informally to refer to a group of closely spaced volcanic structures located inside an area of about 2000 km2. The complex is part of a north-south volcanic range, most important peaks of which are: the historically active and highest mountain of México, Pico de Orizaba or Citlaltépetl volcano (5700 m) to the south, the Cerro Gordo (3940 m) dacitic dome in the middle and the extinct, highly eroded Cofre de Perote volcano (4250 m) to the north (Figs, 16 and 23). Some morphological features of Las Cumbres, such as U-shaped valleys on the west flank, reflect the activity of glacial erosion during the Late Pleistocene. On the west flank of LCVC (between 2500 and 3500 m a.s.l.) are found Plinian, white-colored púmice fall deposits of rhyolitic composition informally named the Quetzalapa pumice (Rodriguez et al., 1994). Some of the most striking features of these deposits are their unusually large thickness of 15 m and the lack of any associated post-Plinian ignimbrite deposits.

The basement of LCVC is an Upper Cretaceus, highly-folded and faulted limestone which is covered by products from several volcanic sources. The complex was built during four stages of activity with ages ranging between Late Pliocene to Holocene. The first period was characterized by the emission of thick lava flows mainly of andesitic composition. This effusive activity resulted in a huge and widespread volcanic massif which volumetrically constitutes the bulk of the complex (Fig. Geologic map). During thee second stage there was a predominance of dacitic and obsidian domes emplacement, such as Sillatepec, Xalista, El Rodeo, and Ixetal; the last contains a Prehispanic obsidian quarry.

The third episode of activity was characterized by the emplacement of local non-welded pyroclastic flows and regional pumice fall deposits. One of the products of this mainly explosive activity is the voluminous pyroclastic fall deposits of the Quetzalapa pumice that can be seen in quarries, road and stream cuts on the west flank of Las Cumbres. Radiocarbon dates from the base of the Quetzalapa pumice have yielded Late Pleistocene ages.

The third period of activity probably culminated with the formation of one of the most conspicuous structures of the Las Cumbres complex: a circular depression 4.5 km in diameter with a dacitic dome (Cerro Gordo) in the center (Fig. 17). Hoskuldsson (1992) considered this structure as the vent which expelled the Quetzalapa pumice. However, based on evidence inferred from the isopach and isopleth distributions, the lack of pumice inside Las Cumbres depression, as well as information yielded from ballistic materials, the eruptive center of the Quetzalapa pumice might be in a different locatioin, possibly buried under the very material it erupted.

Finally, the fourth and last stage is represented by the activity of monogenetic cones, explosion craters, and dome-like structures, mainly concentrated in the north part of the complex. One of them, the rhyolitic Yolotepec dome has been dated at 5869 +/-60 yr. BP. The products of this fourth stage are interbedded with pyroclastic fall and flow deposits from the recent eruption of Pico de Orizaba volcano.

Considering an area of 2000 km2 and an average thickness of 50 m (including the lavas), the total estimated volume for the volcanic products of the Las Cumbres complex is 100 km3. The purpose of the LCVC excursion is to visit the best outcrop of the unusually thick Quetzalapa pumice deposit, observe its stratigraphic relations with other pyroclastic deposits, and recognize some structural and textural characteristics of the deposit (Fig. 25).

Previous Studies: Most of the previous studies in the area of this excursion refer to surrounding zones such as Pico de Orizaba volcano and Las Derrumbadas domes. Some important references are: Waitz (1910), Yanez-Garcia and Casique-Vasquez (1980), Robin and Cantagrel (1982), Robin et al. (1983), Negendank er al. (1985), Siebe and Verma

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(1988), Rodriguez-Elizarraras and Lozano-Cobo (1991), Siebe (1992), Hoskuldsson (1992), Siebe et al (1993), Hoskuldsson and Robin (1993), Carrasco-Nunez (1993), Carrasco-Nunez et al. (1993), and Rodriguez-Elizarraras et al. (994).

Quetzalapa Pumice: The name "Quetzalapa pumice” is introduced informally for the voluminous pumice fall deposits that are found on the western flank of LCVC. The Quetzalapa pumice consists of two members (Fig. 25): the lower one is massive, clast supported, well to medium sorted, with a high lithic content. The base of the deposit is characterized by reverse grading and its total maximum thickness is 15 m. The upper member is a pyroclastic sequence that starts with a 2 cm thick surge horizon followed by a massive pumice-fall deposit with an average thickness of 50 cm. The sequence is topped by a package with a thickness of 30 to 50 cm, consisting of multiple layers of fall and surge deposits with a strong enrichment of lithics. The pumice is characterized by abundant brown biotite crystals (1-3 mm) with an average content of Si02 of 7170. A minimum estimate for the volume of the Qutzalapa pumice is 10 km3 (dense rock equivalent).

Figure 26 corresponds to the isopach map and the isopleths for the mean sizes of the five largest pumice and lithics. The distribution axis has a NNE direction and the most distal data is a horizon of 3 cm of reworked material with abundant biotite located 75 km NE of the vent. Comparing the Quetzalapa with the isopachs and isopleths of the Taupo pumice in New Zealand (Walker, 1980) it is possible to note an off-centered distribution in the isopachs for Taupe, but its isopleths are clearly centered at the vent; while in the case of the Quetzalapa pumice isopachs and isopleths are concentric.

Radiocarbon dating of charcoal within a pyroclastic flow below the pumice yielded ages of 22935 +1505/ -1265 and 24945 +/- 270 y. B. P., and a soil stratigraphically above yielded an age of 18335 +255/-245 y. B.P. Therefore the Quetzalapa pumice fall has an age that ranges between ca. 18000 and ca. 25000 y. B.P.

The Quetzalapa pumice deposits are covered by hornblende-bearing pyroclastic flows which clearly eroded its top. These flows are not genetically related to the biotite-bearing Quetzalapa pumice. They are in turn covered by a hornblende-bearing pumice fall with a thickness between 1 and 2 m. This fall has been dated at 18335 +255/-245 y. B.P. and is probably related to the formation of the Las Cumbres explosion caldera and the emplacement of the Cerro Gordo dome.

At this time several key-questions regarding the age and source of this remarkably young deposit are still uncertain. The exact age is difficult to constrain, because the pumice deposit itself does not contain any charcoal or other datable material. But it is certainly not older than 25000 y., nor younger than 18000 y.

The source of this un it is still totally unknown, which for a deposit of this young age and large extent is incredible, A larger crater should be expected. At this time three possible locations are under investigation: a) Las Cumbres crater, b) Las Derrumbadas rhyolite domes, and c) a vent possibly located between a) and b) buried under lacustrine and volcaniclastic deposits.

Las Derrumbadas rhyolite dome complex and associated explosion craters: Growth and sequential gravitational collapse of major monogenetic domes

Although rhyolitic volcanism appears to be unusually frequent in many areas of the TMVB, not much attention has been devoted to this phenomenon. Instead the more magnificent strato-volcanoes of andesitic and dacitic composition have been the main focal points of volcanological research. However, interest in the occurrence of rhyolitic rocks has increased in the last years for several reasons. Foremost among them has been their frequent link to exploitable high-enthalpy geothermal energy resources. Additionally, population growth in central Mexico increases the need for more comprehensive models identifying volcanic hazards related to various types of rhyolite eruptions, including the emplacement of large monogenetic domes.

The closed basin of Serdán-Oriental and its Quarternary rhyolite volcanic structures (e.g. Cerro Pinto, Cerro Pizarro, Las Derrumbadas domes, Cerro Xa]apaxco, Tepexitl and San Luis Atexcac tuff rings), offer a unique possibility for stepwise reconstructing the detailed sequence of volcanic events that control the growth and collapse of major monogenetic silicic domes.

Las Derrumbadas twin rhyolitic domes, with fumarolic activity and extensive rock alteration are situated in the middle of the closed basin of Serdan-Oriental (Figs. 27 and 28). They are of importance due to their geothermal potential and were studied in detail by the Comisión Federal de Electricidad (e.g., Yañez-García and Casique, 1980). Additional investigations were carried out by Siebe (1985) and Siebe and Verma (1988) during which a new type of debris avalanche deposit that promised a deeper insight into the mechanisms regulating dome growth and destruction was recognized. For these reasons an investigation of these domes with emphasis on the debris avalanche deposits was undertaken (Siebe et al, 1992; 1993).

The debris avalanche deposits occur on all sides of the Las Derrumbadas domes and consist of a chaotic mixture of all sorts of materials including not only blocks of faulted surge and pyroclastic flow deposits, but also enormous (decimeters in size) blocks of non-volcanic origin such as Cretaceus limestone and partly consolidated lake sediments. The deposits are quite extensive, reach as far as 7 km from the domes, and typically display a hummocky topography. A simplified map after Siebe (1985) is shown in Fig. 28.

The Las Derrumbadas rhyolite domes contrast with other large domes worldwide, e.g. Mount Lamington (Taylor, 1958), Bezymianny (Gorshkov, 1959), Lassen (Eppler, 1984) and Santiaguito (Rose, 1972), in that they are not linked to a composite volcano but are monogenetic. Therefore it appears that the Las Derrumbadas domes represent a type of domes that has not been studied in detail previously. This is especially true regarding the formation of a polymict carapace and its later collapse into a polymict, chaotic debris avalanche deposit.

These puzzling deposits are debris-avalanche deposits related to the partial collapse of the domes. In conjunction, all other domes and volcanic structures nearby in the area were studied. They offered several clues regarding the origin of the non-volcanic materials within the debris avalanche deposits of Las Derrumbadas. These include the domes Cerro Pinto, Cerro Pizarro, as well as the tuff-rings Tepexitl, Laguna Atexcac and the tuff-cone Cerro Xalapaxco (Figs. 27 and 28).

Preliminary field and laboratory studies show that all of the above rhyolite structures represent the final volcanic products of individual pods of magma of the same mineralogical and chemical composition(SiO^2 >70% - biotite, plagioclase and almandine in glassy matrix), which reached the Earth's surface in recent time and in the same geologic and geographic environment. Since so many factors that commonly influence the eruptive style of rising magma appear to be almost identical for the formation of the various domes in the Serdán-Oriental basin, it becomes clear that the volume of magma erupted played the main role in determining the final morphology of the different structures in the area. This ideal situation makes it possible to envisage the smaller volcanic edifices as early "frozen" stages of growth in the evolution of more mature complex rhyolite domes. Preliminary integral observations at all these structures allow the recognition of a general evolutionary sequence that encompasses three distinctive stages of growth (I, II, 111) and two stages of collapse (IV, V) for the Las Dernrmbadas rhyolite domes.

The five different evolutionary stages are named here after those volcanic edifices that best exemplify the main characteristic features of each stage and are briefly described below (see also Fig. 29):

<u>Stage I (Laguna Atexcac and Tepexitl explosion craters):</u> Laguna Atexcac and Tepexitl craters are Late Pleistocene/Holocene tuff rings 900-1000 m in diameter. Laguna Atexcac erupted 3 km to the north of the Las Derrumbadas domes and presently contains a lake. Tepexitl is located SE of the domes (see Figs. 27, 28 and 30) They were formed almost entirely by phreatomagmatic activity when a small amount of rhyolite magma came in contact with enough groundwater or shallow surface water. The initial explosive eruptions produced an explosion breccia, which is overlain by dune- and planar-bedded pyroclastic surge deposits intercalated with ash-fall layers. The surge deposits were mostly "wet" and contain blocks of juvenile obsidian which show flow-banding. Additionally, the surge deposits contain numerous blocks of local bedrock such as Cretaceous limestone and terrigenous and lacustrine sediments.

<u>Stage 11 (Cerro Xalapaxco):</u> Cerro Xalapaxco is a tuff-cone 2-3 km in diameter located to the north of Cerro Pinto. It shows a similar pyroclastic sequence as Laguna Atexcac. The main difference resides in its much bigger size and the lack of a lake. Additionally, most of the surge deposits were emplaced in a "dry" environment.

Stage 111 (Cerro Pinto): Cerro Pinto is a rhyolite dome surrounded by a tuff-cone of the same size and nature as Cerro Xalapaxco. The dome has a glassy and pumiceous carapace partly overlain by surge deposits and blocks of local bedrock carried upward during emplacement.

Stage IV (Las Derrumbadas NW dome): This dome rises more than 1000 m above the surrounding plains and has a volume of approximately 6-7 km^3. The dome almost entirely lacks a carapace and consists chiefly of a grey, microcrystalline rhyolite that has been altered in many areas due to fumarolic activity. Additionally, this dome is surrounded by extensive debris-avalanche deposits with a hummocky topography and multilobate outline. These debris-avalanche deposits contain a chaotic mixture of blocks of all sizes including crumbled lacustrine sediments and surge deposits, Cretaceus limestone, and grey banded obsidian in a whitish clayey matrix. These blocks are interpreted to be the only remnants of a former tuff-ring, tuff-cone, and glassy carapace, since any other in situ evidence has disappeared as a result of mass wasting processes. The debris avalanche deposits are partly covered by thin surge deposits in their more distal parts, which suggests that their emplacement was accompanied by explosive activity.

Stage V (Las Derrumbadas SE dome): This dome has the same height as the NW dome and displays many of its characteristics. It is surrounded by the multilobate, humrnocky debris-avalanche deposits of the first generation as well as by more recent dry-rock debris avalanche deposits that partly cover the older ones. The recent debris avalanche deposits have quite different characteristics. They are not as extensive, form morphologically elongate tongues with steep fronts and have flat surfaces. Additionally they are less coarse and consist almost entire] y of the grey, microcrystalline rhyolite from the core of the dome. Relatively fresh-looking horseshoe-shaped scars high on the domes suggest a recent formation. They show areas of intense alteration into kaolinite related to weakening of the edifice after prolonged fumarolic activity. These avalanches were probably triggered by earthquakes and presently active fumaroles at several spots suggest possible ocurrence of other avalanches in the future. Vast areas on the flanks of both domes are covered by alluvial fans formed as a result of sheet-flooding after heavy storms.

In conclusion, integral observations at all these structures allow the recognition of a general evolutionary sequence that encompasses three distinctive stages of growth (1, 11, 111) and two stages of collapse (IV, V). During stage I a small tuff ring is formed by phreatomagmatic activity characterized by the emplacement of "wet" surge deposits. During Stage 11 this tuff ring is enlarged in diameter and a tuff cone consisting mostly of "dry" surge deposits is formed. Later a glassy dome with a pumiceous carapace partly overlain by surge deposits and local bedrock carried upward is emplaced within the tuff ring (stage III). Continuous extrusion of glassy rhyolite lava leads to slope instability of the dome and emplacement of debris avalanches.

At least 8 individual debris avalanche deposits were identified and classified into basically two different (ypes. First generation deposits are older and originated from 60-900 sector collapse. They are heterolithologic in composition and include blocks of such diverse lithologies as limestone, lacustrine sediments, juvenile obsidian, dismembered surge deposits from the former tuff cone, etc. They display a typical hummocky topography, have H/L ratios of 0.1 and maximum runout distances of 9 km (stage IV).

The last stage of activity is characterized by fumarolic activity and the emplacement of second generation debris avalanches. Second generation deposits occur stratigraphically hihger and originated from 20-300 sector collapses. They cover smaller areas and also have smaller runout distances of 4.5 km with H/L ratios around 0.2. They are monolithologic in composition, consisting of grey microcrystalline rhyolite ($SiO2 > 70$ %, biotite, plagioclase and almandine in a glassy matrix), and are less coarse than first generation deposits. In addition they form elongated tongues with flat surfaces and have steep terminal scarps (stage V).

Field and laboratory studies indicate that the domes were formed during a relatively short time span. Comparison of Las Derrumbadas with other rhyolite structures in the area facilitated an interpretation of the origin of both types of avalanche deposits. The heterolithologic first generation deposits were formed at an earlier evolutionary stage when the domes were still carrying a carapace of glassy obsidian and rocks from the local basement such as Cretaceus limestone and lacustrine sediments. The monolithologic second generation debris avalanche deposits were formed later when the caps were stripped to expose the microcrystalline juvenile cores of the domes. At present, fumarolic activity is weakening the stability of the slopes and second generation debris avalanche deposits might occur again in the future.

Road Log

0.0 km — Exit Tlachichuca to the east and take the unpaved road to Avalos, located 7 km to the southeast. In a small barranca 200 m south of Avalos is stop 4-1.

7.0 km — Stop 4- I: At this stop a good outcrop showing the deposits that form the block-and-ash fan at the western slope of Pico de Orizaba will be visited. The model of eruption oultined above will be discussed in relation to the recent glacial history of the area for possible hazards analysis in the event of renewed volcanic activity. A schematic stratigraphic section of the outcrop to be visited is shown in Fig. 20.

18.0 km — Return to Tlachichuca. Before entering Tlachichuca turn right towards the north on the paved road to Guadalupe Victoria. After 5 km arrive at a junction and turn right towards the NE on the road to Paso National. After another 5 km arrive in Paso National. A big quarry can be seen across the barranca. Take the unpaved road that leads to the quarry. After 1 km you will arrive at the big quarry (Stop 4-2), which displays the Quetzalapa pumice and associated deposits (see also Figs. 24 and 25).

38.0 km Return to the paved road and to the main road downvalley. Before arriving at Sta Inés Varelas, a great panoramic view over the Serdán-Oriental basin can be obtained. Cross Sta Inés Varelas and arrive at the junction. Turn right towards Guadalupe Victoria and pass Quetzalapa. After 5 km from the junction turn left on an unpaved road towards the west. Head for 9 km towards the northern tip of the Tepetitlán limestone ridge (see map in Fig. 28 and 30). This is Stop 4-3, which shows the distal surge deposits that formed Tepexitl tuff ring, lying unconformably on top of the Cretaceus limestone.

42 km Continue northwards towards the western rim of'1 'epexitl crater and get as close as possible to the crater rim. This is Stop 4-4. Walk to the crater rim and inspect the outcrops (Fig. 30). Juvenile obsidian in the surge deposits and explosion breccia is abundant. Do not use your hammer unless you are wearing protective glasses. Obsidian is the sharpest material on Earth ! Enjoy the view of the Las Derrumbadas SE dome and its debris avalanche deposits.

45 km Continue northeastwards towards the small settlement Bellavista. The road leads directly to the frontal margin of a tongue-shaped debris avalanche deposit from Las Derrumbadas. At the frontal margin is a small gravel quarry. This is Stop 4-5. The quarry shows outcrops displaying the internal structure of this “second generation" debris avalanche deposit, which consists mostly of microcrystalline grey rhyolite gravel. The horse-shoe shaped car, where the deposit originated can also be observed here. Note the reddish color at the scar, which is due to hydrothermal alteration.

62 km Continue northeastwards and reach Bellavista. From here take the road that exits the settlement to the north and continue for about 10 km along a dirt road that winds through

the hummocky terrane of Las Derrumbadas "First Generation" debris avalanche deposits. Reach the paved road that connects Guadalupe Victoria with San Luis Atexcac and turn left to the northwest in direction of San Luis Atexcac. After 7 km on this road, shortly before reaching San Luis Atexcac, exit the paved road to the left and take a small dirt road that leads near the crater rim of San Luis Atexcac maar. Park the car and walk 5 minutes upslope. This is Stop 4-6. Enjoy the view of the turquoise-green lake and inspect the deposits that form the crater. On the western crater wall it is possible to observe Cretaceous limestone and the remnants of a basaltic scoria cone that were partially destroyed during the formation of the tuff ring (see Fig. 31). Juvenile material in the surge deposits consists of rhyolitic obsidian. Xenoliths consisting of basaltic scoria, Cretaceous limestone, tertiary monzonite, contact metamorphic hornfels from the local basement arc abundant within the surge deposits and explosion breccias.

75 km ' Return to the paved road and turn left. After 2 km reach the junction with highway 140. Turn left towards the southwest in direction of Zacatepec. After 11 km park at the side of the road in the vicinity of large hummocks of Las Derrumbadas "first generation" debris avalanche deposits. This is Stop 4-7. Inspect the hummocks and outcrops showing their internal structure. Note the great variety of lithologies, including surge deposits, Cretaceus limestone, etc.

127 km Drive back on highway 140 and continue northeastward to Perote at the northern margin of the Serdán-Oriental basin, where we will spend the night.

Day 5: Late Pleistocene and Holocene explosive volcanism in the Serdán-Oriental basin 11.

During this day several volcanic structures and their deposits located in the interior and at the southwestern margin of the Serdán-Oriental intermontane basin will be visited. We will first visit Alchichica maar, and Cerro Pinto rhyolite dome complex. The second half of the day will be devoted to La Malinche strato-volcano and Xalapaxco tuff cone at its base. At the end of the day we will drive back to the Mexico-City International airport.

La Malinche Volcano, the unknown giant sleeper

a Tertiary -Quaternary andesitic stratovolcano that reaches 4503 m in altitude and is believed to be extinct (Heine, 1975) (Figure 32).

Xalapasco, an unusual tuff cone with multiple explosion craters

The Xalapaxco tuff cone is located on the southwestern edge of the Serdán-Oriental Basin near the base of the northeast flank of La Malinche (Figures 32 and 33). About a dozen other phreatomagmatic explosion craters occur in the Serdán-Oriental intermontane basin (Siebe, 1986), several of which bear either the name Xalapaxco or Axalapaxco depending on whether or not they contain a lake in their crater. *Xalapaxco is* a word in Nahuatl (the language spoken by the Aztecs) meaning vessel or container made of sand. An *Axalapaxco* is a vessel made of sand that contains water. Therefore the term *Xalapaxco* can be envisaged as the equivalent of a tuff cone or dry tuff ring, and *Axalapaxco as* a maar.

Ordoñez (1905, 1906) was the first to study tuff rings in the Serdán-Oriental intermontane basin and to recognize that they were phreatomagmatic in origin. Xalapaxco is in many respects a typical tuff cone, But the large number (10) of explosion craters, which indent its surface is unusual Figs. 34 and 35). A survey of the literature revealed that no other place in the world has a similar tuff cone with so many craters,

The explosion craters are concentrated on the central and on the uphill side of the cone, and expose alternating beds of stratified surge. deposits and massive fall deposits. The morphology of the cone and the characteristics of its deposits point to the involvement of significant quantities of groundwater during its eruption. The phreatomagmatic eruptions which led to the cone's formation pierced an alluvial fan, the source of which, is a glacially carved canyon near the summit of La Malinche volcano. The large canyon was cut during repeated glacial episodes, the last of which ended ca. 8,500 years ago. The present alluvial fan mostly consists of reworked glacio-fluviatile andesite/dacite material from La Malinche. Rising magma encountered substantial amounts of groundwater within the limestone basement and in overlying intercalated pyroclastic and glacio-fluviatile deposits of the alluvial fan. Short-lived phreatomagmatic eruptions produced surge and airfall deposits (Fig. 36). Xenoliths found in the cone beds are composed of dacite and andesite clasts, limestone, chert, and rare ignimbrite fragments. No juvenile material could be unequivocally identified, but is represented most probably by porphyritic dacite similar in texture and composition to La Malinche lavas.

The multiple craters were formed as a response to changes in water and magma supply during the short-lived eruption. Hence the locations where ideal magma/water ratios existed to fuel phreatomagmatic explosions shifted in time and space. Analysis of diameter/depth ratios of the craters indicates that the activity shifted from the center of the cone to its periphery in the west. Due to the configuration of the hydrographic environment, more groundwater flowing from La Malinche was available from the fan on the uphill side than below the cone at later stages of the eruption. The apparently anomalous position of the tuff cone on the slopes of a stratovolcano in a presently dry environment can be explained by more humid climatic conditions prevailing at the time of eruption. The above is an excerpt from Abrams and Siebe (1994).

It is the purpose of this stop to discuss and speculate about the possible origin of Xalapaxco´s multiple craters.

In conclusion, we infer that the Xalapaxco tuff cone formed when rising magma encountered sufficient volumes of ground water in the. alluvial fan heading from the glacial valley on the east side of La Malinche volcano, as well as in the saturated Cretaceus limestone basement. A suggested cross-section through the cone (Figure 37) shows the lowest basement material to be folded Cretaceous limestone, as evidenced by limestone and chert clasts found as exotic inclusions in the Xalapaxco tuff cone strata, and the nature of nearby limestone outcrops. Overlying the limestone beds are most probably a series of fluvial layers intercalated with pyroclastic flow and air fall deposits. The volcanic products found in the fluvial layers are from La Malinche volcano; these are dominantly reworked gray and reddish andesite and dacite gravels, with rare rhyolites. Overlying the volcanic and fluvial deposits is the most recent glacio-fluvial outwash debris forming the alluvial fan; this is made up of subangular to round fragments of the La Malinche andesites and dacites. During the eruption, Xalapaxco tuff cone sampled all of the underlying basement materials, incorporating sand, cobbles, and boulders as xenoliths, and ejecting some of them as bombs. For this reason it is also possible that particles observed under the SEM received their rounded and pitted character during, transport as the alluvial deposits accumulated and not necessarily during explosive recycling during eruptions. The vents themselves are currently filled with slump debris from mass wasting of the steep walls into the pits.

A schematic history of the formation of the Xalapaxco tuff cone is as follows: Global climatic changes during the Quaternary resulted in development of major glacial episodes, affecting the high volcanic peaks in central Mexico. The last major glaciation of the summit of La Malinche occurred about 8,000 to 10,000 yr BP. During the glacial stages a deep glacial canyon was carved on the northeast flank of the volcano. Warming climate caused the glaciers to melt, leaving a deep incised canyon, Barranca Axaltzintle, at the headwater of a drainage. Alluvial and reworked glacio-fluvial materials were deposited as a triangular-shaped alluvial fan on the flak of La Malinche. On the other sides of the volcano, parallel, incised drainages developed, cutting into the pyroclastic deposits, also found below the alluvial fan. Continued volcanic activity at La Malinche resumed when rising magma ascended through the limestone basement, pierced intercalated fluvial and pyroclastic layers, and finally breached the alluvial fan to erupt on the surface. The magma encountered large volumes of water, particularly in the alluvial fan "which acted as an aquifer that was fed by a large area of the volcanic edifice. Other sources of groundwater were in the limestone basement, which has high permeability and could form karstic voids; and in the overlying intercalated fluvial and pyroclastic beds. High water/magma ratio, estimated between 0.5 and 1.0 (Wohletz and Heiken, 1991), produce phreatomagmatic eruptions of moderate explosivity at shallow depths. Eruptions were short-lived, as evidenced by the lack of soils between beds. Construction of the cone was by way of base surges and fall deposits. The juvenile magma was most probably porphyritic dacite similar in composition to La Malinche lavas. After cessation of eruptive activity, the cone has been modified by erosion, producing small gullies on the sides; and by slumping of material into the craters, partially filling them.

The peculiar setting of the Xalapaxco tuff cone on the flanks of a stratovolcanoes is explained by the interaction of magma and groundwater under more humid climatic conditions. Under normal, drier conditions, or in a drier environment, Xalapaxco might have formed as a dacite dome. However, because of the presence of a glacio-fluvial alluvial fan, storing and channeling large quantities of water, ascending magma reacted phreatically to produce a tuff cone. It is therefore possible to at least partially atribute the formation of Xalapaxco to the peculiar configuration of hydrologic conditions that prevailed during the last glacial stage in this area.

Roadlog Day 5

00.0 km Exit Perote to the southwest and take the highway 140 again in direction of Zacatepec.

27.0 km After 27 km park your car on the right side of the road at the rim of Alchichica maar. This is Stop 5- I . Alchichica is the largest maar crater in the Serdán-Oriental. The juvenile components of its deposits consist of scoriaceous basaltic or basaltic andesite. From the eastern crater rim a good view of a dissected scoria cone at the western crater rim can be obtained. Note the tuffa deposits at the shore of the lake.

40.0 km Continue on highway 140 towards the southwest, After 3 km turn right on the dirt road to Itzoteno. After 4 km on this road arrive in Itzoteno, cross the town and exit it on a dirt road to the southwest. After 6 km arrive at the eastern crater rim of Xalapaxco tuff cone, located to the north of Cerro Pinto rhyolite dome. This is Stop 5-2, one of the best outcrops in the area showing "dry" surge deposits. Note cross-bedding, impact sags of bombs, and other typical features of surge deposits.

42.0 km Continue southwards on the same dirt road, cross the interior of Xalapaxco and arrive at a major quarry on the northern slopes of Cerro Pinto dome. This is Stop 5-3. The quarry is operated by a company that mines perlite (hydrated obsidian) at this place. Note the explosion breccias, surge deposits and their relationship to the Cerro Pinto dome.

138.0 km Drive hack to Itzoteno and to highway 140. At highway 140 turn right and drive 22 km to Zacatepec. From here continue on highway 58 for 15 km northwestwards to El Carmen, You will cross Laguna Totolcingo salt lake, which is the remnant of a large lake that once occupied the Serdán-Oriental. At El Carmen continue towards the west and reach Huamantla after 32 km. Enter Huamantla and exit it again to the south on the highway towards Puebla. After 9 km arrive in Ixtenco. In Ixtenco take the unpaved road that exits the town towards the west. Drive upslope La Malinche volcano for 3 km and arrive at a junction. Turn right towards the north and arrive after 3 km at the western base of Xalapaxco tuff cone. Take the the road that leads towards its summit and arrive at the rim of the largest of its multiple explosion craters. This is Stop 5-4, Park the car and inspect the area (see also Figs. 34, 35, and 36).

From the eastern rim of the main crater a great view of the entire southwestern part of the Serdán-Oriental can be obtained.

147.0 km Continue on the same dirt road towards the east and finish circling Xalapaxco until you arrive again at the paved highway. Return in the direction of Huamantla. After 1 km turn left to the west on the road to Los Pilares. Arrive in Los Pilares and follow a dirt road leading into the barranca El Pilar. Follow the road for 500 m within the barranca and arrive at a large rivercut. This is Stop 5-5, which shows a series of Late Pleistocene and Holocene pyroclastic flow deposits from La Malinche (see stratigraphic section in Fig. 38).

155.0 km Return to Los Pilares and lake the dirt road exiting the town to the west to Guadalupe Altamira. After 5 km reach the paved road at Guadalupe Altamira and turn left towards Albergue Malintzin. After 3 km arrive at Stop 5-6, which is a roadcut on the left side of the road. Here, very young ash-flow deposits with abundant charcoal and poor soil development on top crop out (see stratigraphic sction in Fig. 38). The young appearance of these deposits suggests that Malinche erupted during Holocene time and should therefore be regarded as potentially active and presently in a state of dormancy.

159.0 km Cent inue towards the west for another 5 km and reach a junction. Turn left and arrive at Albergue Malintzin. From here take the dirt road that leads southwards uphill for about 500 m. Park the car and walk 100 m to the west, where a sinkhole produced by a caterpillar exposes young pyroclastic flow deposits from La Malinche. This is Stop 5-7 (see also stratigraphic section in Fig. 38).

312.0 km Return to Albergue Malintzin and take the paved road northward for 9 km to San José Teacalco. Here take the road to the northwest to Coaxomulco for another 9 km. Exit Coaxomulco to the west and continue 4 km to San Miguel Contla and another 4 km to Amaxac. In Amaxac take the road southwestwards 8 km to Tlaxcala. Here take the new freeway 28 km to San Martín Texmelucan, where you have to enter the federal freeway 190 D to Mexico-City. After 91 km arrive in Mexico-City and follow the signs to the airport.

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Below the main summit is the northwestern glacier with deep transverse crevasses. The glacier represents a water reservoir with potential for contributing to lahar generation. Photograph taken by Hugo Delgado, May 1986.

Fig. 6: Sketch map of Popocatépetls' summit area showing dimensions of the crater and location of fumaroles as they appeared prior to the December 21, 1994 eruption.

Fig. 7: Idealized stratigraphic column for Popocatépels' Late Pleistocene and Holoene eruptive products cropping out on the road to Paso de Cork% and Tlamacaz.

Fig. **8: Stratigraphic** columns of outcrops at stops 1-1 to 1-10 to be visited during day 1. The oucrops are located on the road to Tlamacaz at the northern and western slopes of Popocatépetl.

Fig. 9: Sketch map showing the approximate extent of debris avalanche deposits at Popocatépetl and Ixtaccíhuatl volcanoes. So far, a total of four debris avalanche deposits have been identified at this volcanic complex.

Fig. 10: Index map and outcrops revealing Pleistocene debris avalanche and associated deposits to be visited during day 2 at the southern slopes of Popocatépetl.

Fig. 11: Idealized stratigraphic column for Popocatépels' debris avalanche deposits and associated eruptive products cropping out on southern flank of the volcano..

Fig. 12: Stratigraphic columns of outcrops at stops 2-1 to 2-9 to be visited during Day 2. The oucrops are located on the southern slopes of Popocatépetl, where the proximal hummocky block-facies of debris avalanche deposits is best displayed.

Fig. 13: Index map and outcrops to be visited during Day 3. Outcrops display Holocene Plinian deposits that destroyed Prehispanic settlements at the northeastern slopes of Popocatépetl.

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Fig. 15: Sketch map showing the Serdtin-Oriental basin and stops to be visited during Day 4 at Pico de Orizaba volcano, Las Cumbres complex, Las Derrumbadas domes, Tepexitl explosion crater and Atexcac maar, as well as Day 5 at Laguna Alchichica maar, Cerro Pinto dome, and La Malinche volcano.

Fig. 16: Sketch map showing the Cofre de Perote-Las Cumbres-Pico de Orizaba-Sierra Negra volcanic chain as well as other Quaternary volcanic structures located in the basin of Serdán-Oriental (from Siebe, 1992).

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Fig. 18: Perspective view showing the western slopes of Pico de Orizaba volcano and block-and-ash fan F at its base. Other features are: San Miguel Zoapan Z, Cerro Ahuatepec,

A and glacial cirque G. The image combines Landsat Thematic Mapper image data and digital topographic data.

Fig. 19: Sketch map of the western slopes of Pico de Orizaba showing major block-and-ash fan and other morphological features, towns, and Stop 4-1 near Avalos, (after Siebe et. al., 1993).

Fig. 20: Stratigraphic column at Stop 4-1 showing block-and-ash flow deposit lying on top of laharic and fluviatile reworked deposits. Abundant charcoal (sample 9004-B) dated at 4660 ± 100 y. B.P. was obtained at the base of the block-and-ash flow deposit.

Fig. 21: Simplified preliminary risk map of the area showing towns and settlements that would be endangered in case of recurrence of block-and-ash flows and lahars similar to those that formed the presently existing fan (From Siebe et al., 1993).

Fig, 22: Profile showing energy lines for actual and hypothetical block-and-ash flows with the same H/L ratio of 0.23. Where the topographic slope is greater than the energy line the flows accelerate and erode, Where the topographic slope is lower than the energy line the flows decelerate and deposition occurs (From Siebe et al., 1993).

Fig 23: Pico de Orizaba volcano **P,** and Las Cumbres volcanic complex L, as seen from the road from San Luis Atexcac to Guadalupe Victoria,

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Fig. **25:** Stratigraphic section of the Quetzalapa pumice fall and associated deposits at Paso National.

Fig. **26:** Preliminary isopach map for the Late Quarternary Quetzalapa Plinian Pumice fall deposit.

Fig. 27: Landsat Thematic Mapper TM image showing the NW-SE aligned chain of rhyolite domes and phreatomagmatic craters Cerro Tepexitl **Al,** Laguna San Luis Atexcac maar A2, Cerro Xalapaxco tuff cone **B,** Cerro Pinto dome C, and Las Derrumbadas rhyolite domes **E** and **F**. Other geologic features include: Createceous limestone K, Cerro Tecajete basaltic cinder cone '1', and Quetzalapa Plinian pumice **Q**. Towns: Zacatepec Z, and Guadalupe Victoria G.

Fig. 28: Sketch map of the Las Derrumbadas-Cerro Pinto rhyolite dome complex and location of stops to be visited during days 4 and 5. Bold Letters indicate rhyolite domes and phreatomagmatic craters: Cerro Tepexitl **Al,** Laguna San Luis Atexcac maar A2, Cerro Xalapaxco tuff cone B, Cerro Pinto dome C, Laguna Alchichica maar D, and Las Derrumbadas rhyolite domes E and F.

Fig. 29: Schematic representation of main evolutionary tages of rhyolite dome growth and collapse in the Serdán-Oriental basin.

Fig. 30: Sketch map and profile showing Tepexitl tuff ring and associated geologic features.

Fig. 31: Sketch map and profile showing Laguna Atexcac maar crater and associated geologic features.

Fig. 32: Landsat Thematic Mapper satellite image of the area around La Malinche volcano, central Mexico. The image covers an area of about 60 x 60 km, with a resolution of about 30 m. The Xalapaxco tuff cone is the small circular feature X on the east flank of the volcano. Major cities and towns are Puebla P, Huamantla H, Ixtenco I, Tlaxcala T, Amozoc Z, and Apizaco A.

Fig. 33: Excursion stops of day 5 and drainage network map of La Malinche volcano, interpreted from Figure 30. Most of the drainages are parallel and closely spaced, forming a radial pattern around the summit. On the northeast flank, the Xalapaxco tuff cone is situated in a triangular alluvial fan with a marked absence of surface drainage channels (from Abrams and Siebe, 1994).

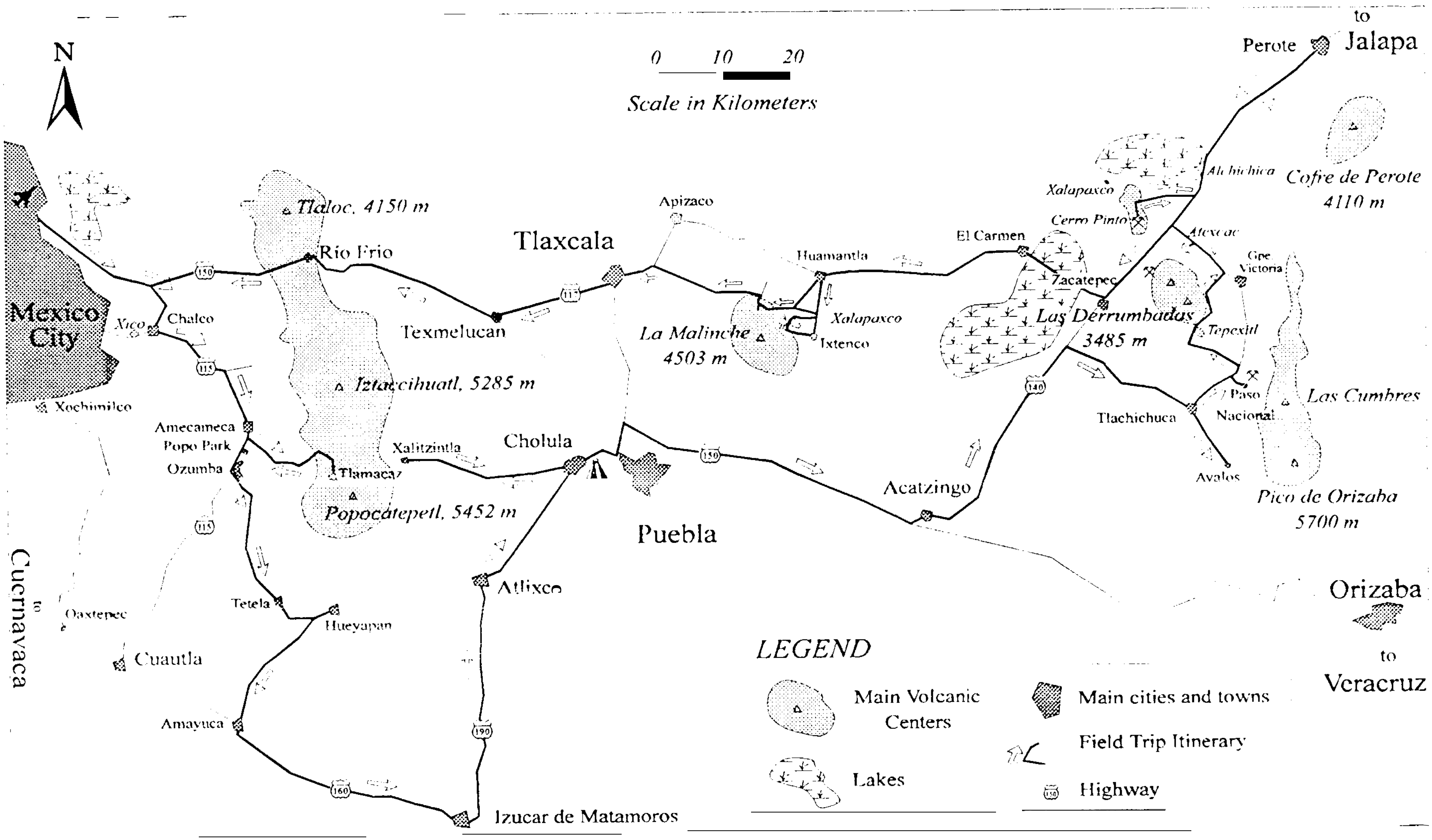
Fig. 34: Xlapaxco tuff cone and its multiple explosion craters as seen from the west.

Fig, 35: Map of the Xalapaxco tuff cone (from Abrams and Siebe, 1994). The map was redrawn from the 1:50,000 scale topographic quadrangle. Six of the craters are named "Hoyas" or clay pots: (1) Hoya Coates (2) Hoya Grande (3) Hoya Las Moneras (6) Hoya San Cristóbal (9) Hoya Las Saucotas (1 O) Hoya Los Texales. Section "A-B" is shown in Figure 34.

Fig. 36: Outcrop within explosion pit Hoya Los Texales showing typical coarse explosion breccia and surge deposits. Surge deposits consist mostly of silt to sand sized clasts. of andesite and dacite. Larger subangular blocks include mostly clasts of andesite and dacite, but xenoliths of chert, limestone, and welded tuff are also present. 'Young enthusiastic geologist for scale. ,

Fig. 37: Interpretative cross-section of the Xalapaxco tuff cone. The underlying basement consists of Cretaceus limestone; above are intercalated fluvial layers and pyroclastic flow and air fall deposits from La Malinche. On top is the most recent glacio-fluvial fan debris, which provided an aquifer and a source for water, thus leading to explosive phreatomagmatic activity (From Abrams and Siebe, 1994).

Fig. **38:** Stratigraphic columns of outcrops at stops 5-5, 5-6, and 5-7 to be visited at the end of Day 5. The oucrops are located on the northern and northeastern slopes of La Malinche and show Holocene pyroclastic deposits.



Siebe et al. Fig.

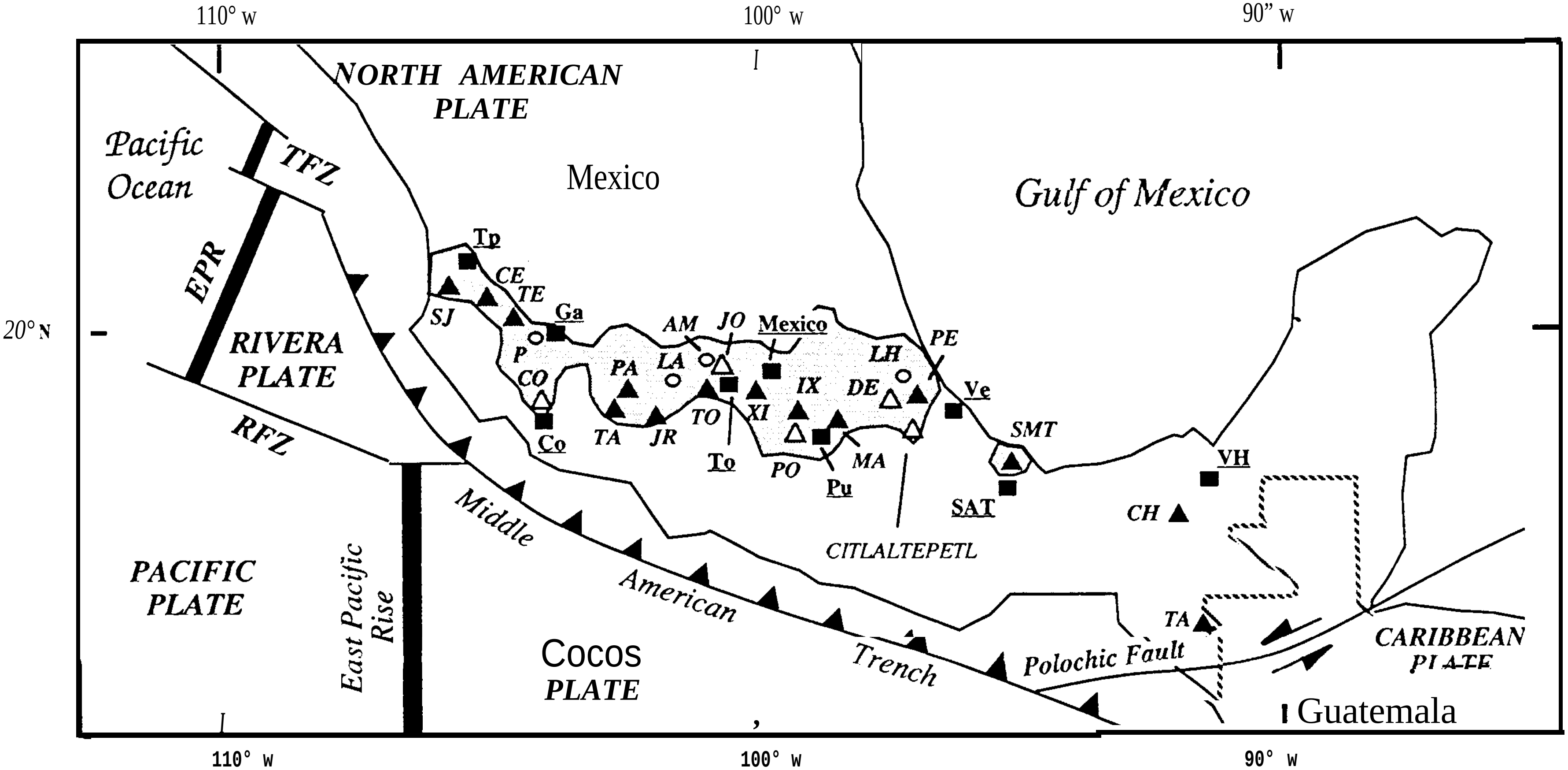


Figure 1: Genera! tectonic setting of Mexico and the Trans-Mexican Volcanic Belt. Quaternary volcanoes with known debris avalanche deposits A : CO Colima; *PO* Popocatépetl; ***DE*** Las Derumbadas ; Citlaltépetl; *JO* Jocotitlán; Other quaternary volcanoes ▲ : ***SJ*** San Juan: ***CE*** Ceboruco: *TE* Tequila: *PA* Paricutín; *TA* Tancítaro; *JR* Jorullo; *TO* Nevado de Toluca; ***XI*** Xitli; ***IX*** Ixtaccíhuatl; ***MA*** Malinche; *PE* Perote; *SMT* San Martín Tuxtla; ***CH*** Chichonal; *TA* Tacaná; Calderas o: *P* Primavera; LA Los Azufres; *AM* Amealco; ***LH*** Los Humeros. Cities ■ : **Tp** Tepic; **Ga** Guadalajara; Co Colima, To Toluca, Pu Puebla, Ve Veracruz, SAT San Andres Tuxtla; VH Villa Hermosa. Tectonic features: ***EPR:*** East Pacific Rise; *TMZ:* Tamayo Fracture Zone; *RFZ:* Rivera Fracture Zone.

Fig. 2 Siebe et al.

X
G
I
A
P
Pu
Ar
L
W
J
Iz
AX
H

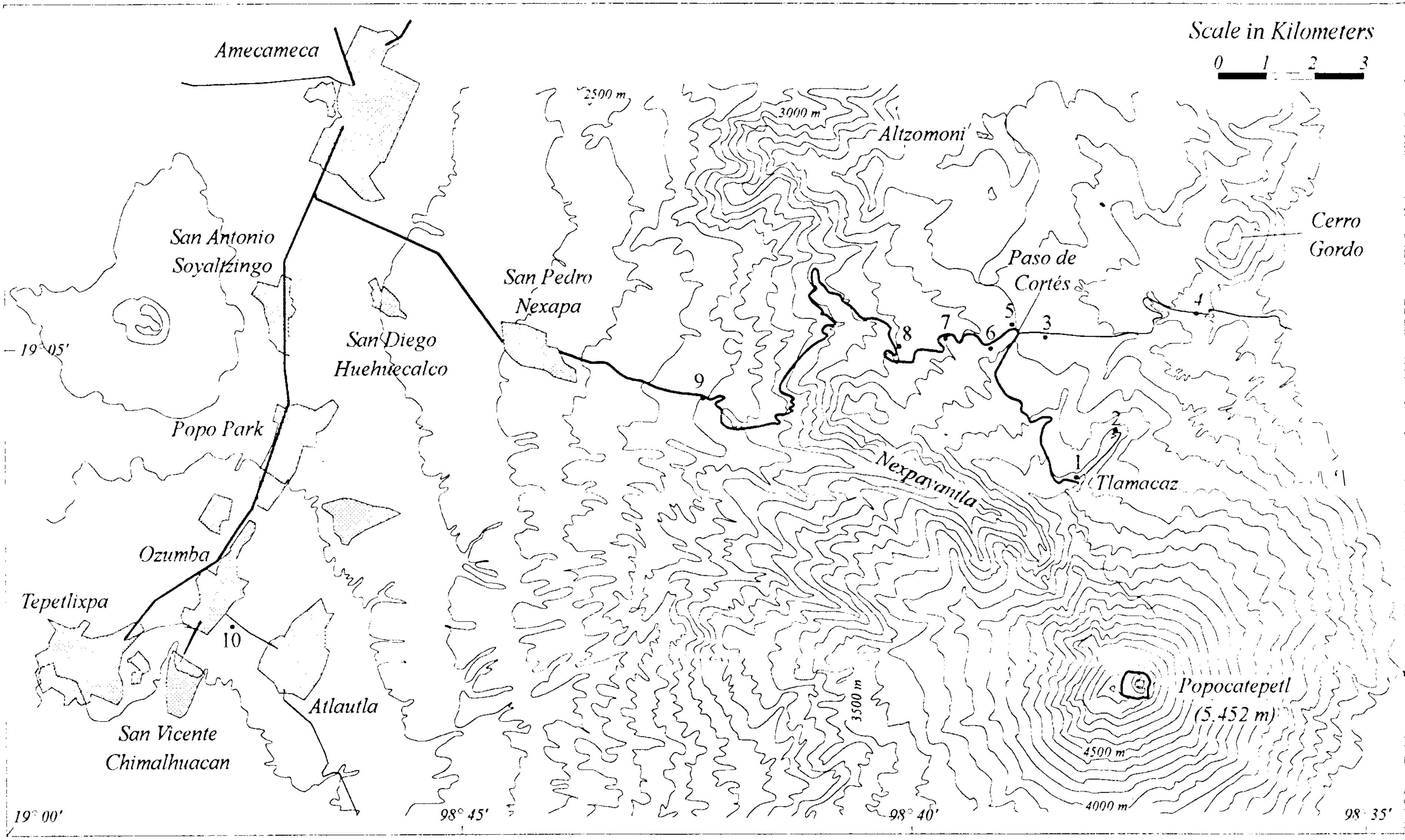
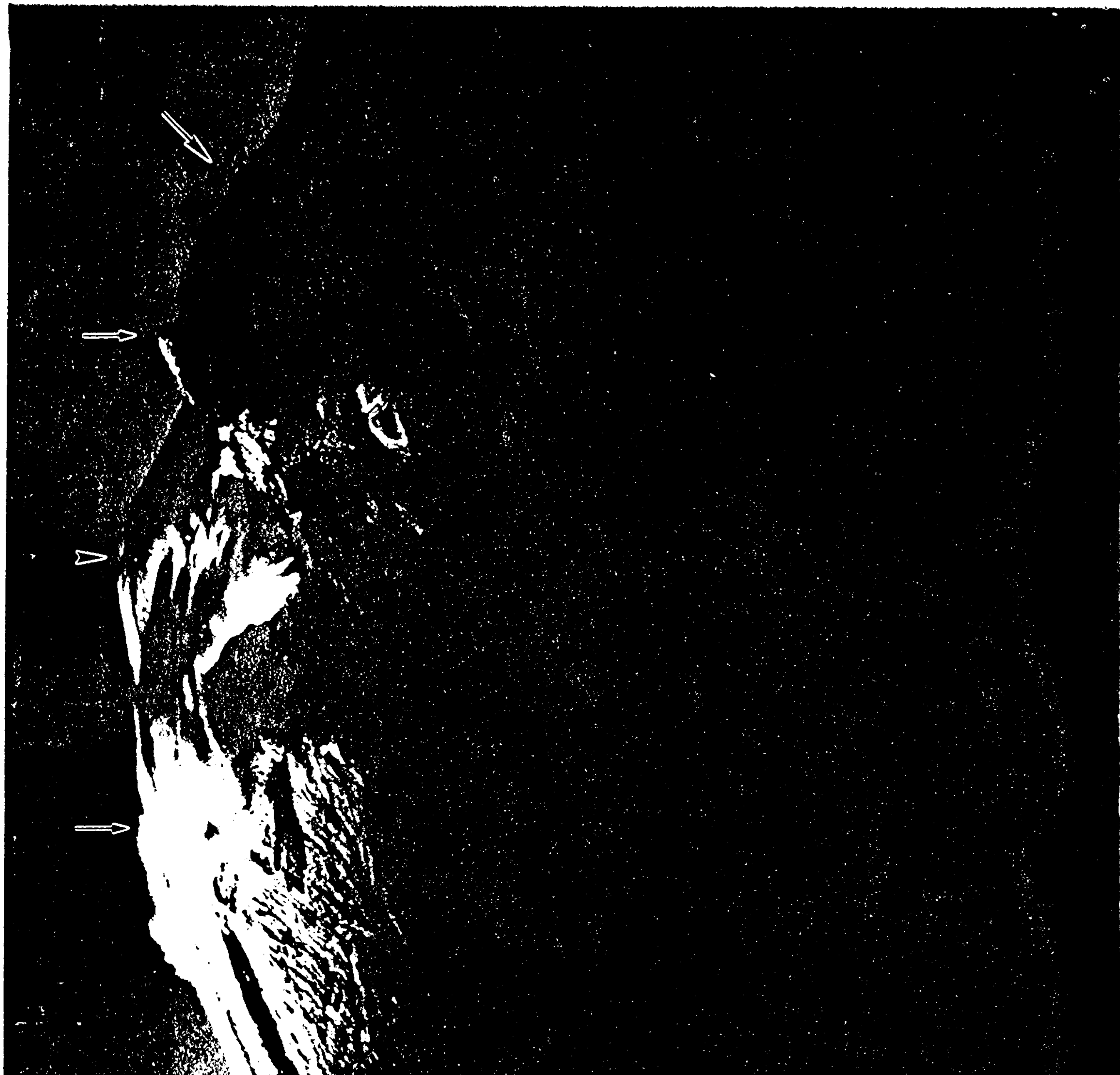
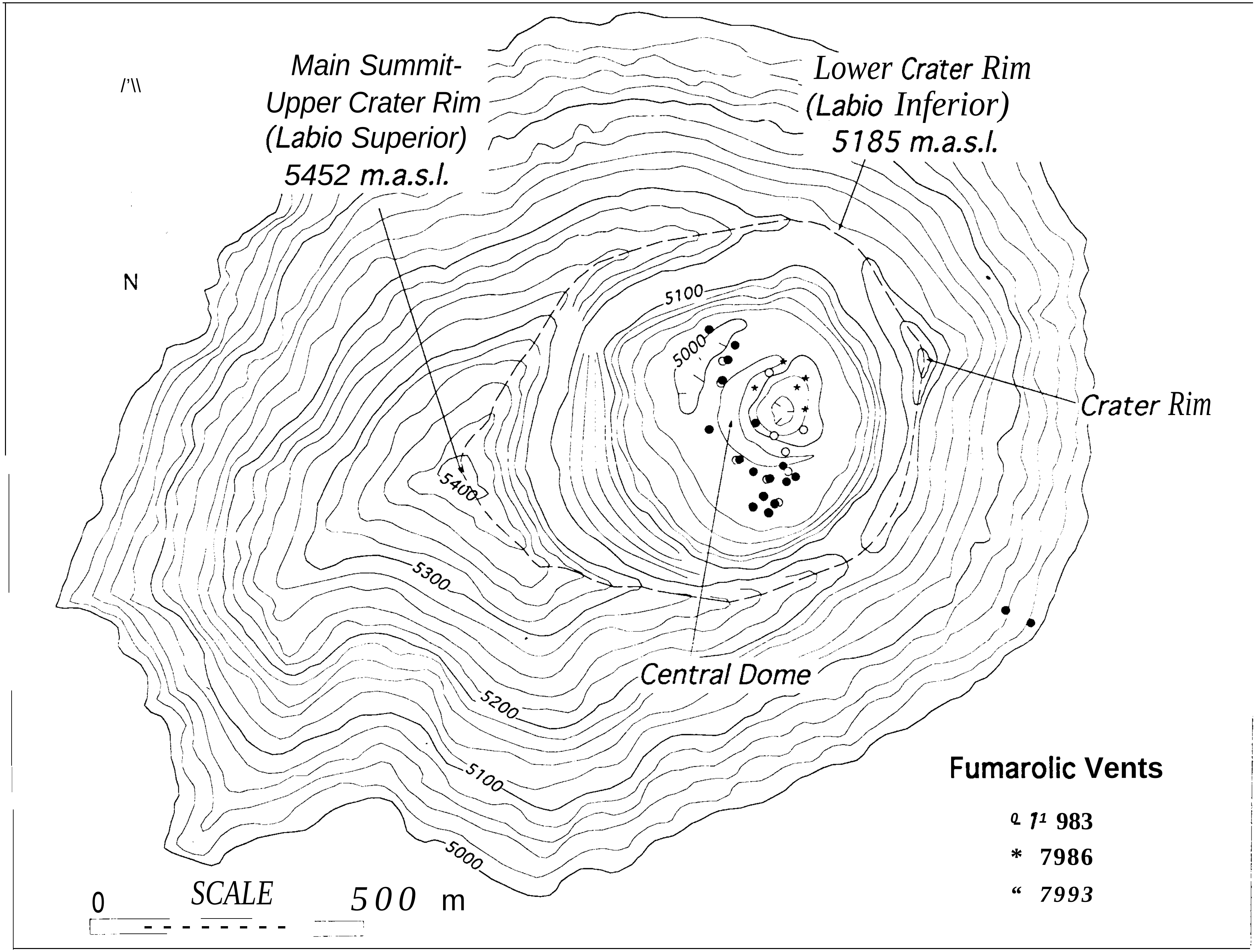


Fig 4. Siebe et al, 1995





Main Summit-
Upper Crater Rim
(Labio Superior)
5452 m.a.s.l.
Lower Crater Rim
(Labio Inferior)
5185 m.a.s.l.
N
5100
5000
5400
5300
5200
5100
5000
Crater Rim
Central Dome
Fumarolic Vents
1 983
* 7986
" 7993
0
SCALE
500 m

Idealized Composite Stratigraphic Section of Popocatépetl Volcano for the last 20,000 y.

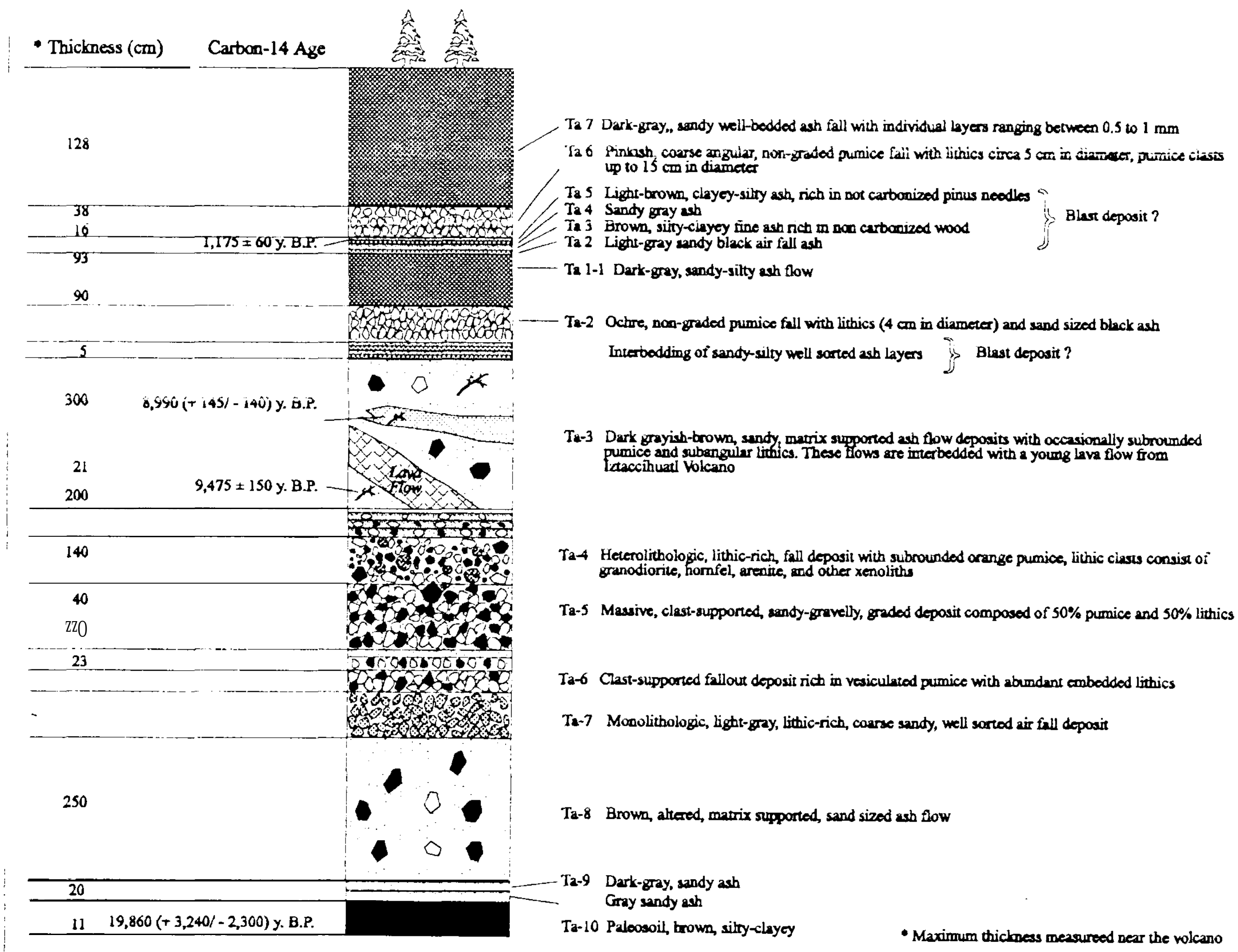


Fig. Siebe et al.

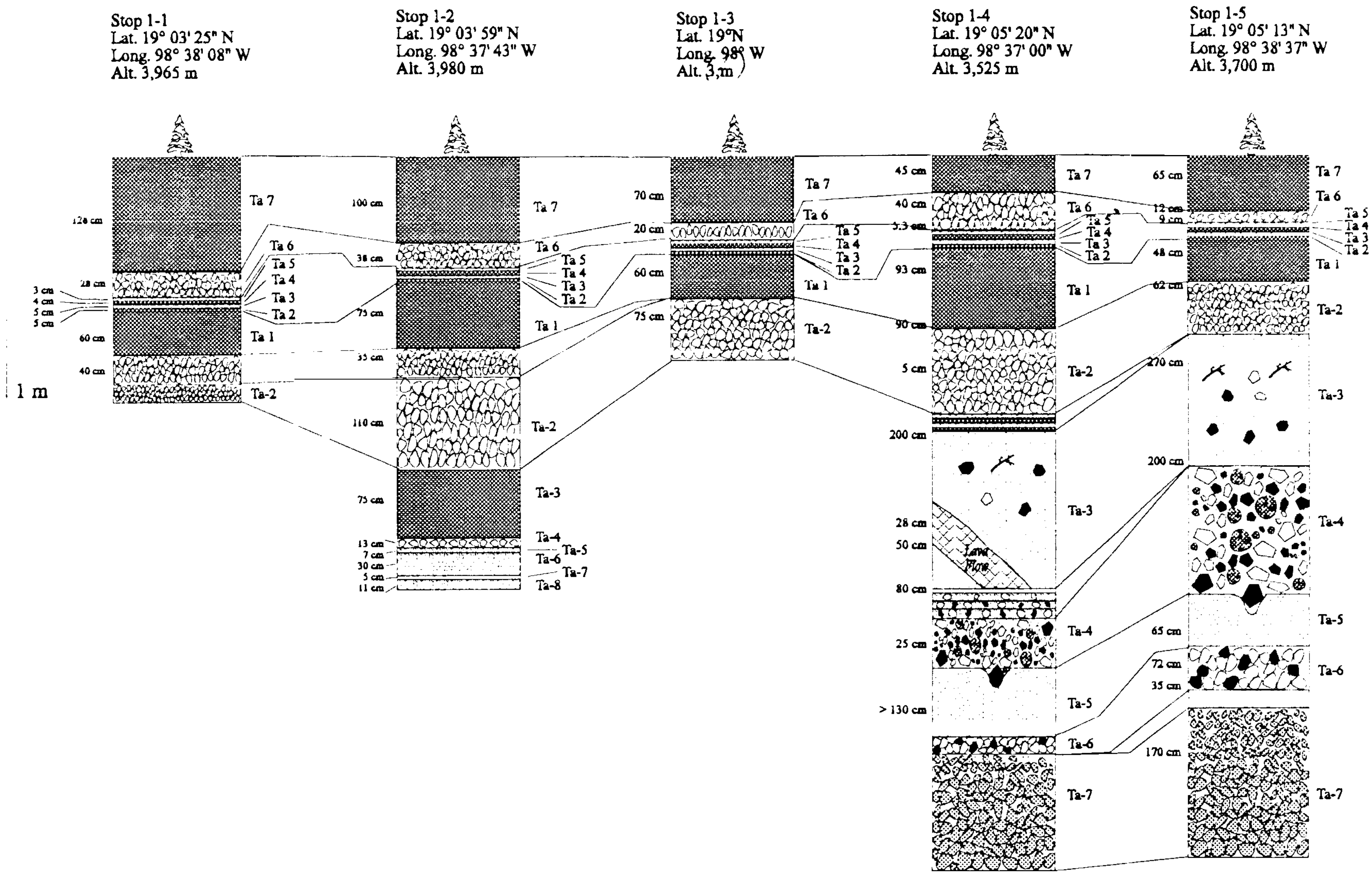
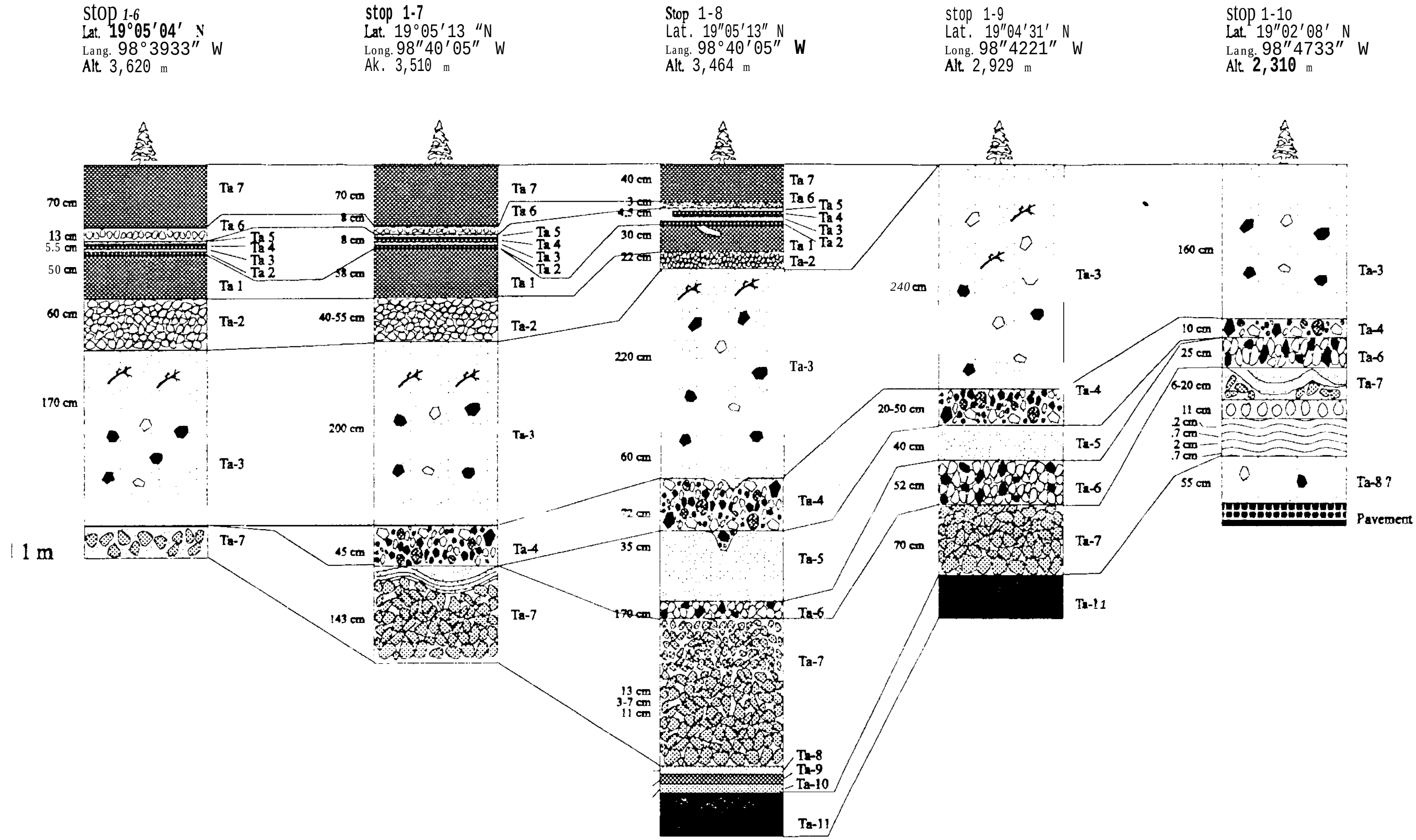


Fig 8 Siebe et al.



stop 1-6
Lat. 19°05'04' N
Lang. 98°3933" W
Alt. 3,620 m
stop 1-7
Lat. 19°05'13 "N
Long. 98"40'05" W
Ak. 3,510 m
Stop 1-8
Lat. 19"05'13" N
Lang. 98°40'05" W
Alt. 3,464 m
stop 1-9
Lat. 19"04'31' N
Long. 98"4221" W
Alt. 2,929 m
stop 1-1o
Lat. 19"02'08' N
Lang. 98"4733" W
Alt. 2,310 m
70 cm
13 cm
5.5 cm
50 cm
60 cm
170 cm
Ta 7
Ta 6
Ta 5
Ta 4
Ta 3
Ta 2
Ta 1
Ta-2
Ta-3
Ta-7
1 m
40-55 cm
200 cm
45 cm
143 cm
Ta-4
40 cm
3 cm
4.5 cm
30 cm
22 cm
220 cm
60 cm
72 cm
35 cm
170 cm
13 cm
3-7 cm
11 cm
Ta-5
Ta-6
Ta-8
Ta-9
Ta-10
Ta-11
240 cm
20-50 cm
52 cm
160 cm
10 cm
25 cm
6-20 cm
2 cm
.7 cm
55 cm
Ta-8 7
Pavement

Approximate extent of *Iztaccihuatl-Popocatepétl* Debris Avalanche Deposits

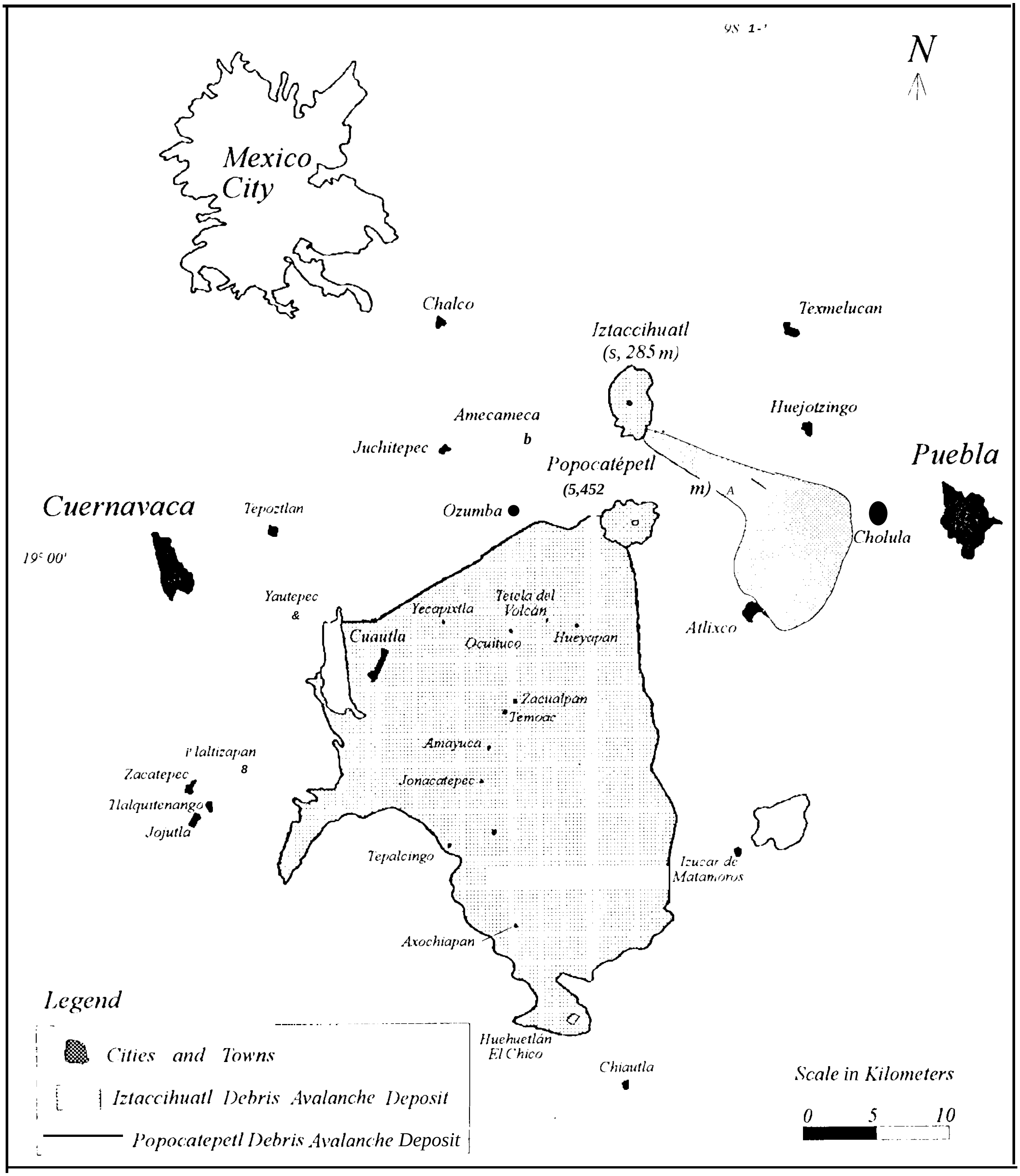
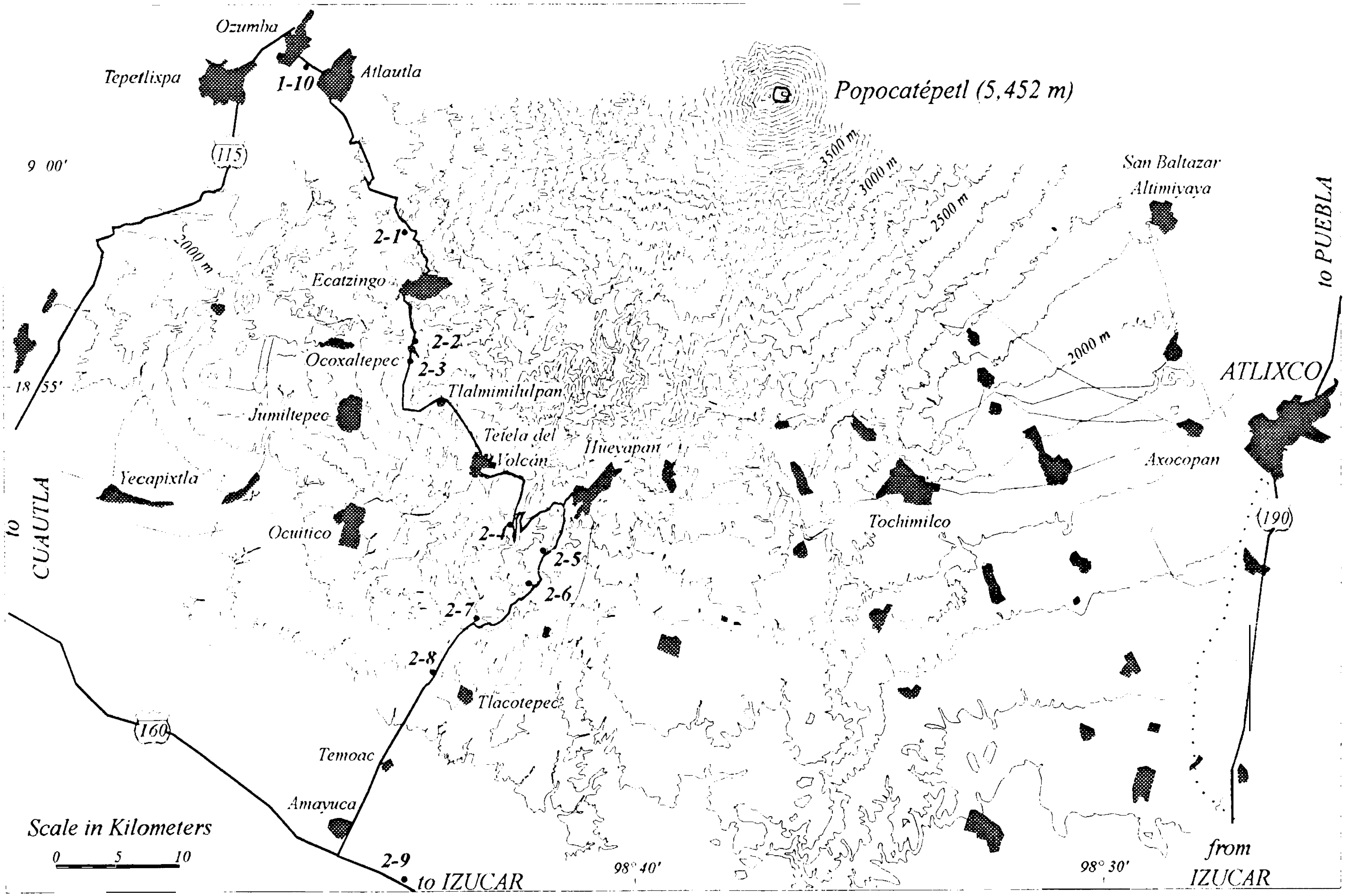


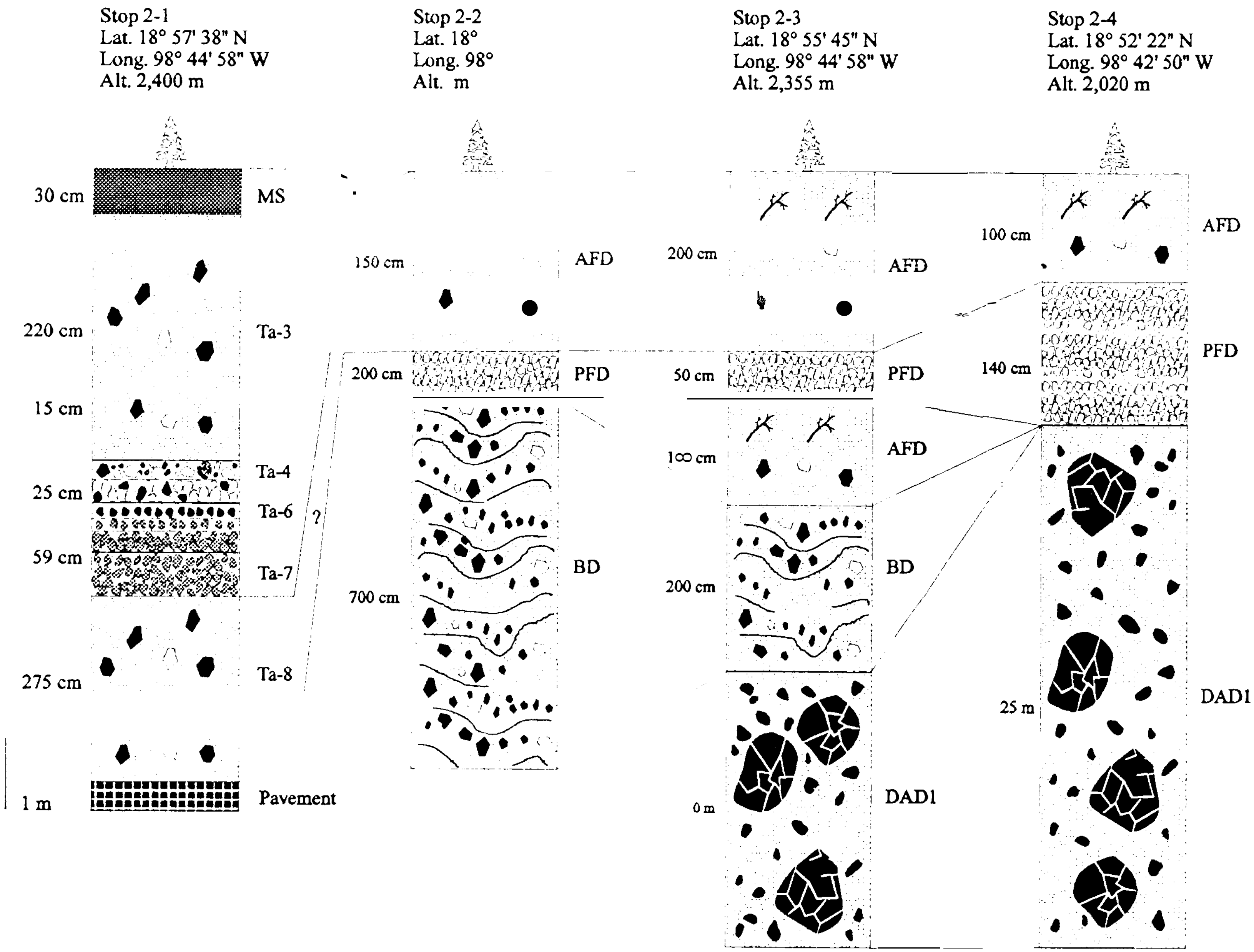
Fig 9
Siebe et al.

2

Day 3: Debris avalanche and associated deposits at the southern slopes of Popocatépetl Volcano

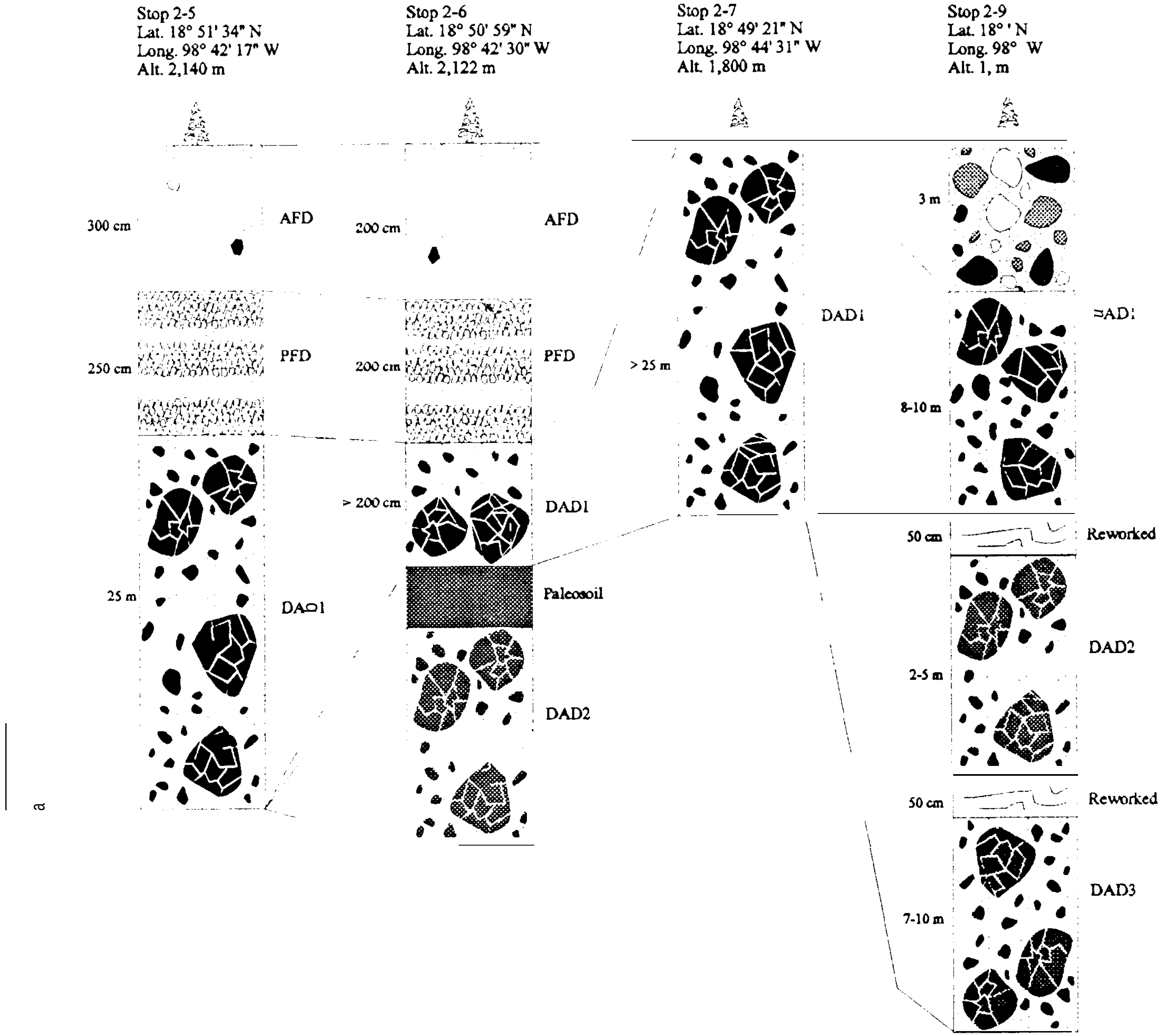


(= still [illegible] !)



Stop 2-1
Lat. 18° 57' 38" N
Long. 98° 44' 58" W
Alt. 2,400 m
30 cm
MS
220 cm
Ta-3
15 cm
Ta-4
25 cm
Ta-6
59 cm
Ta-7
?
275 cm
Ta-8
1 m
Pavement
Stop 2-2
Lat. 18°
Long. 98°
Alt. m
150 cm
AFD
200 cm
PFD
700 cm
BD
Stop 2-3
Lat. 18° 55' 45" N
Long. 98° 44' 58" W
Alt. 2,355 m
200 cm
AFD
50 cm
PFD
100 cm
AFD
200 cm
BD
0 m
DAD1
Stop 2-4
Lat. 18° 52' 22" N
Long. 98° 42' 50" W
Alt. 2,020 m
100 cm
AFD
140 cm
PFD
25 m
DAD1

12



Stop 2-5
Lat. 18° 51' 34" N
Long. 98° 42' 17" W
Alt. 2,140 m
Stop 2-6
Lat. 18° 50' 59" N
Long. 98° 42' 30" W
Alt. 2,122 m
Stop 2-7
Lat. 18° 49' 21" N
Long. 98° 44' 31" W
Alt. 1,800 m
Stop 2-9
Lat. 18° ' N
Long. 98° W
Alt. 1, m
300 cm
AFD
250 cm
PFD
25 m
DAD1
200 cm
AFD
200 cm
PFD
> 200 cm
DAD1
Paleosoil
DAD2
> 25 m
DAD1
3 m
8-10 m
DAD1
50 cm
Reworked
2-5 m
DAD2
50 cm
Reworked
7-10 m
DAD3

Day 3 : Eastern Slopes of Popocatépetl Volcano

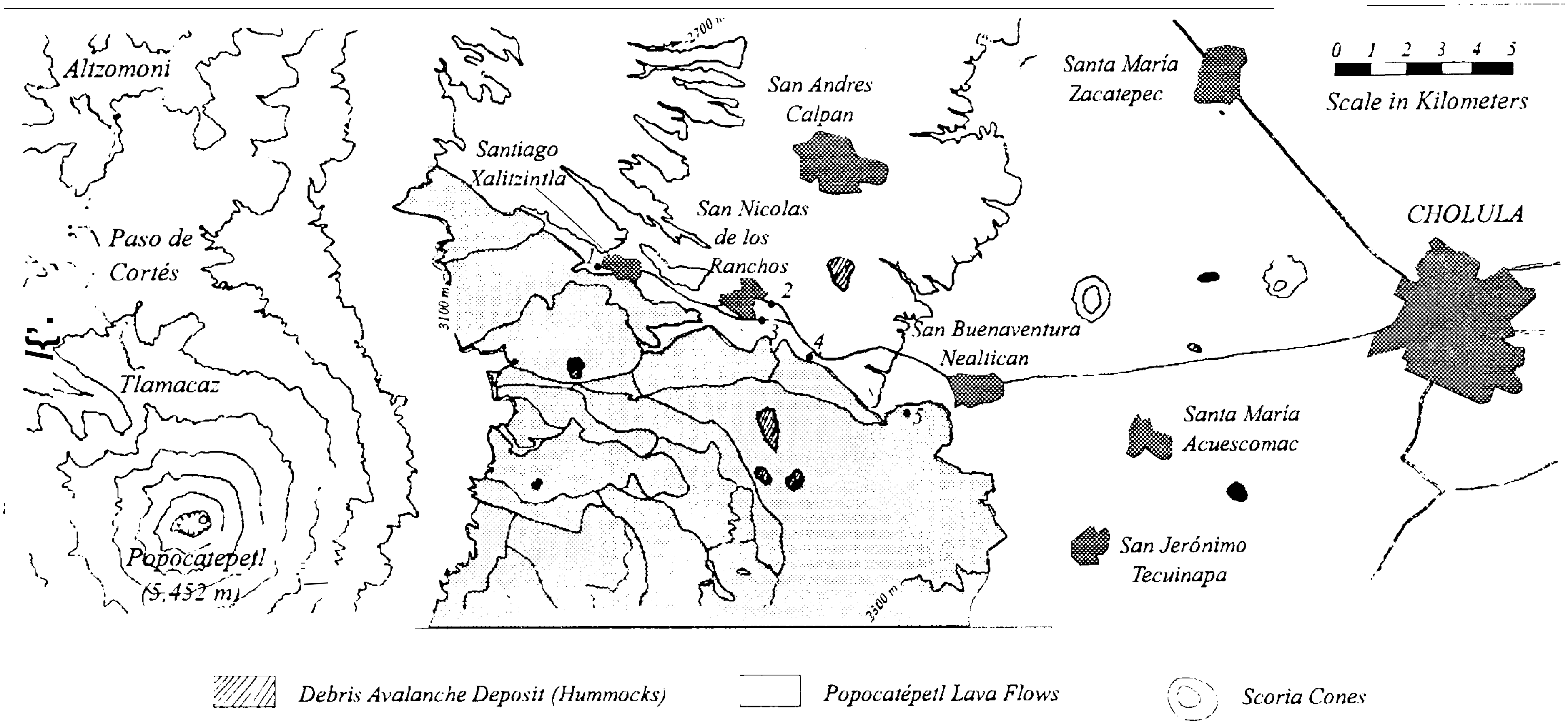
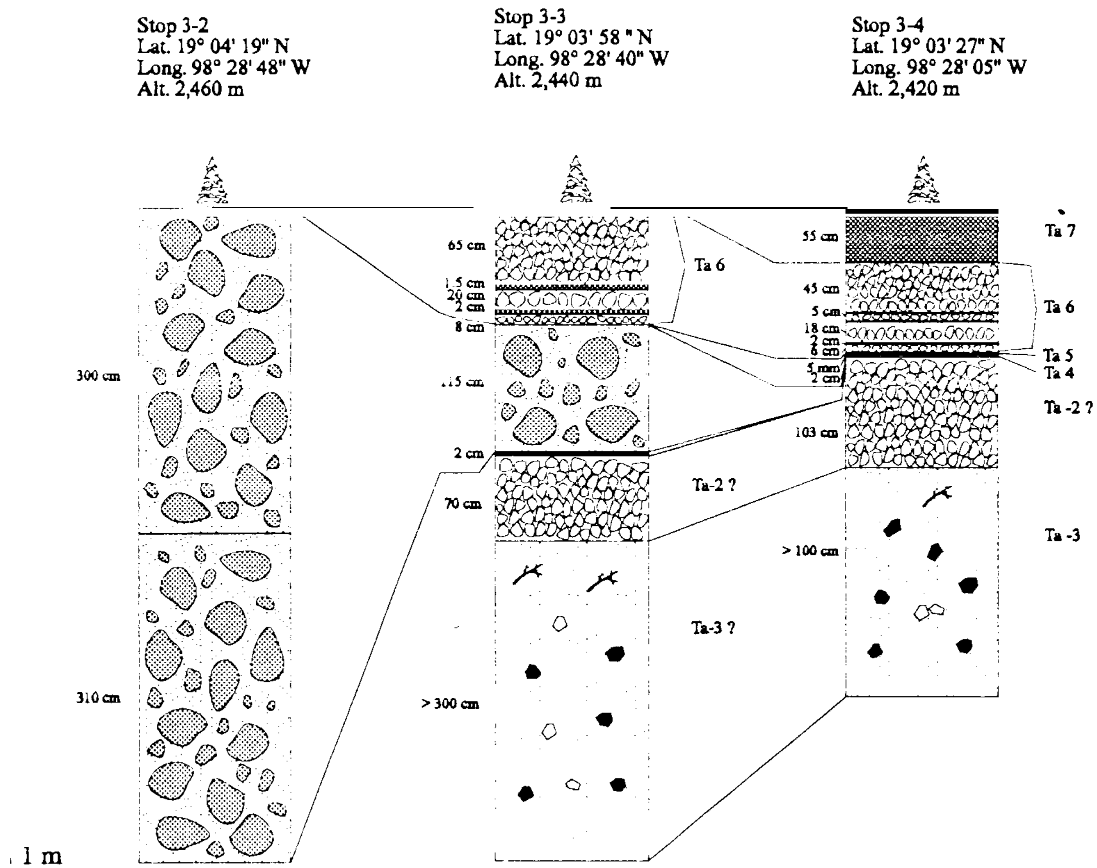


Fig 13 Siebe et al.

Fig. 17. Siebe et al.



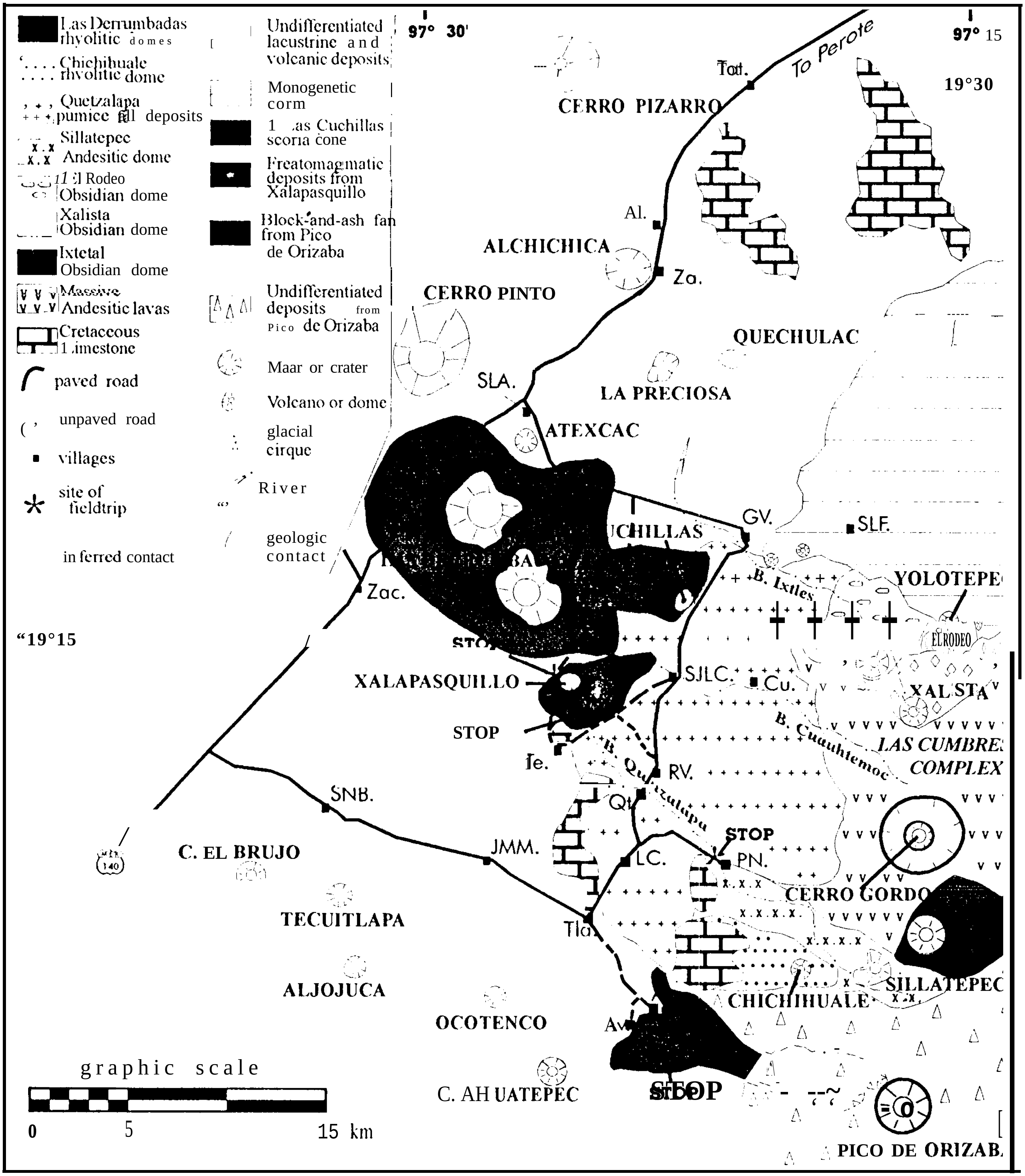
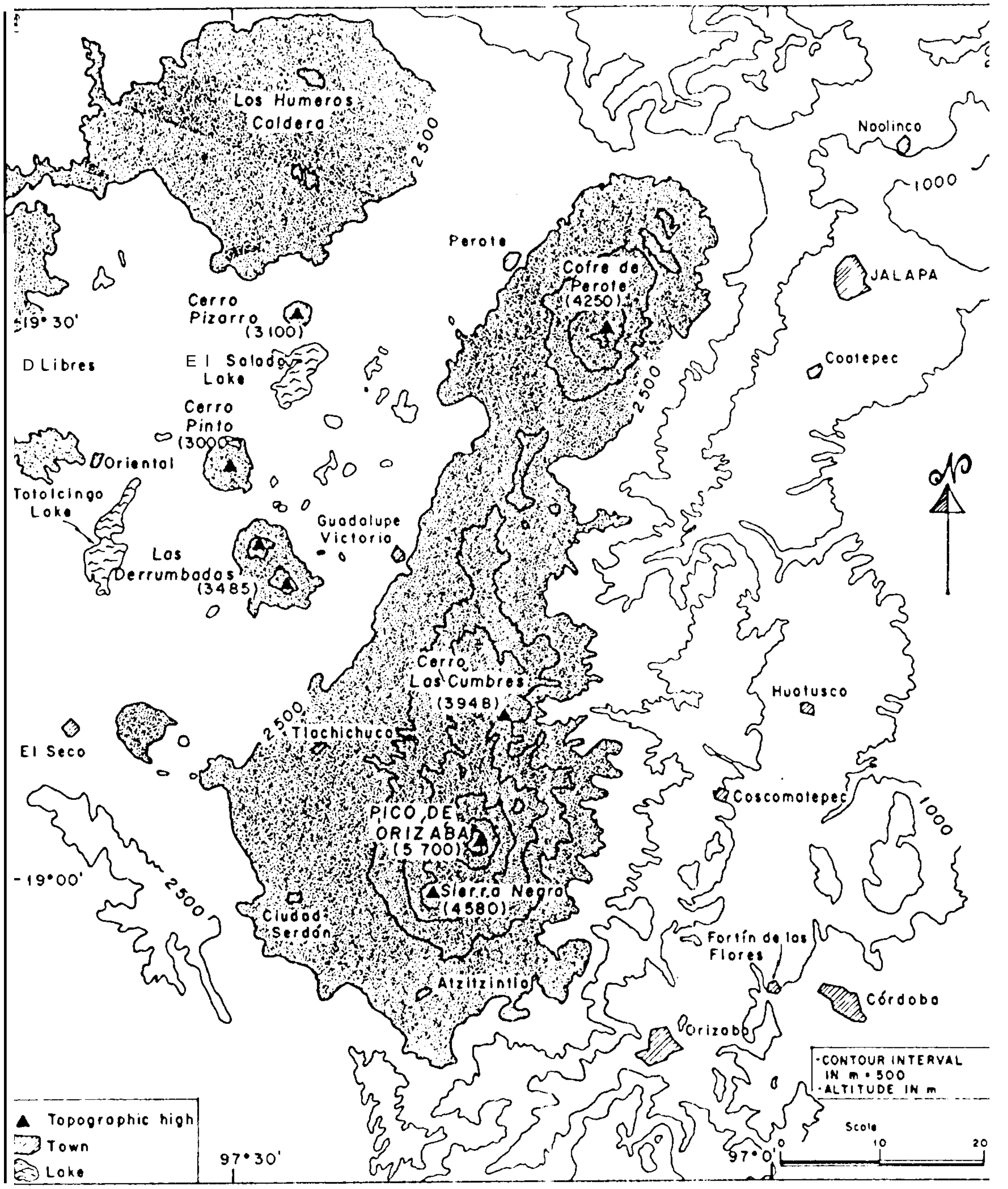


Fig. 17 Siebe et al.



Los Humeros
Caldera
2500
Noolinco
1000
Perote
Cofre de
Perote
(4250)
JALAPA
Cerro
Pizarro
(3100)
19° 30'
D Libres
El Salado
Lake
Coatepec
Cerro
Pinto
(3000)
Oriental
Totolcingo
Lake
Guadalupe
Victoria
Las
Derrumbadas
(3485)
Cerro
Las Cumbres
(3948)
Huatusco
El Seco
2500
Tlachichuca
Coscomatepec
1000
PICO DE
ORIZABA
(5700)
-19°00'
2500
Sierra Negra
(4580)
Ciudad
Serdán
Fortín de las
Flores
Atzitzintla
Córdoba
Orizaba
-CONTOUR INTERVAL
IN m = 500
-ALTITUDE IN m
Topographic high
Town
Lake
97°30'
97°0'
Scale
0
10
20

Fig 6


A
G
T
L
O
K
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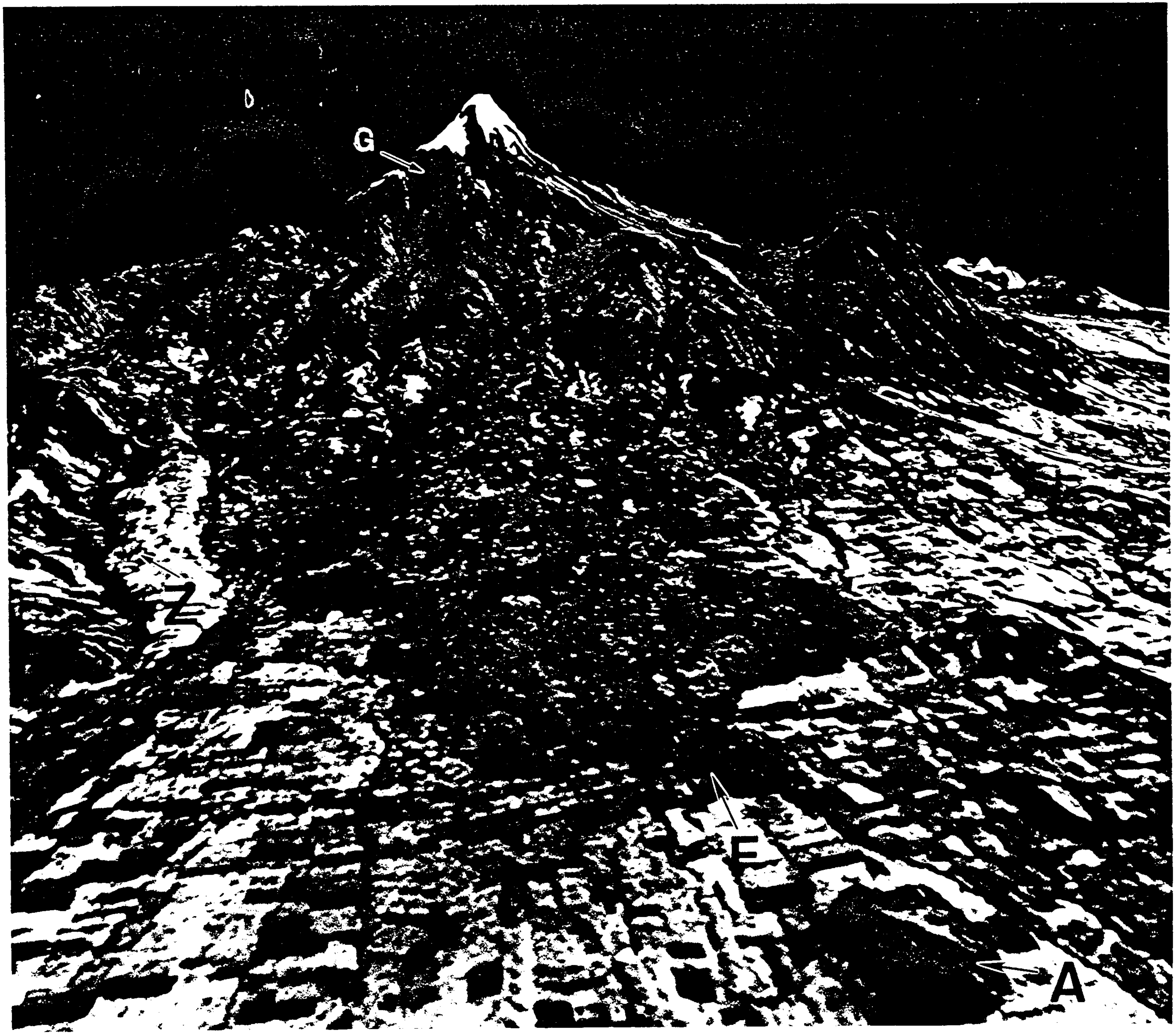
G
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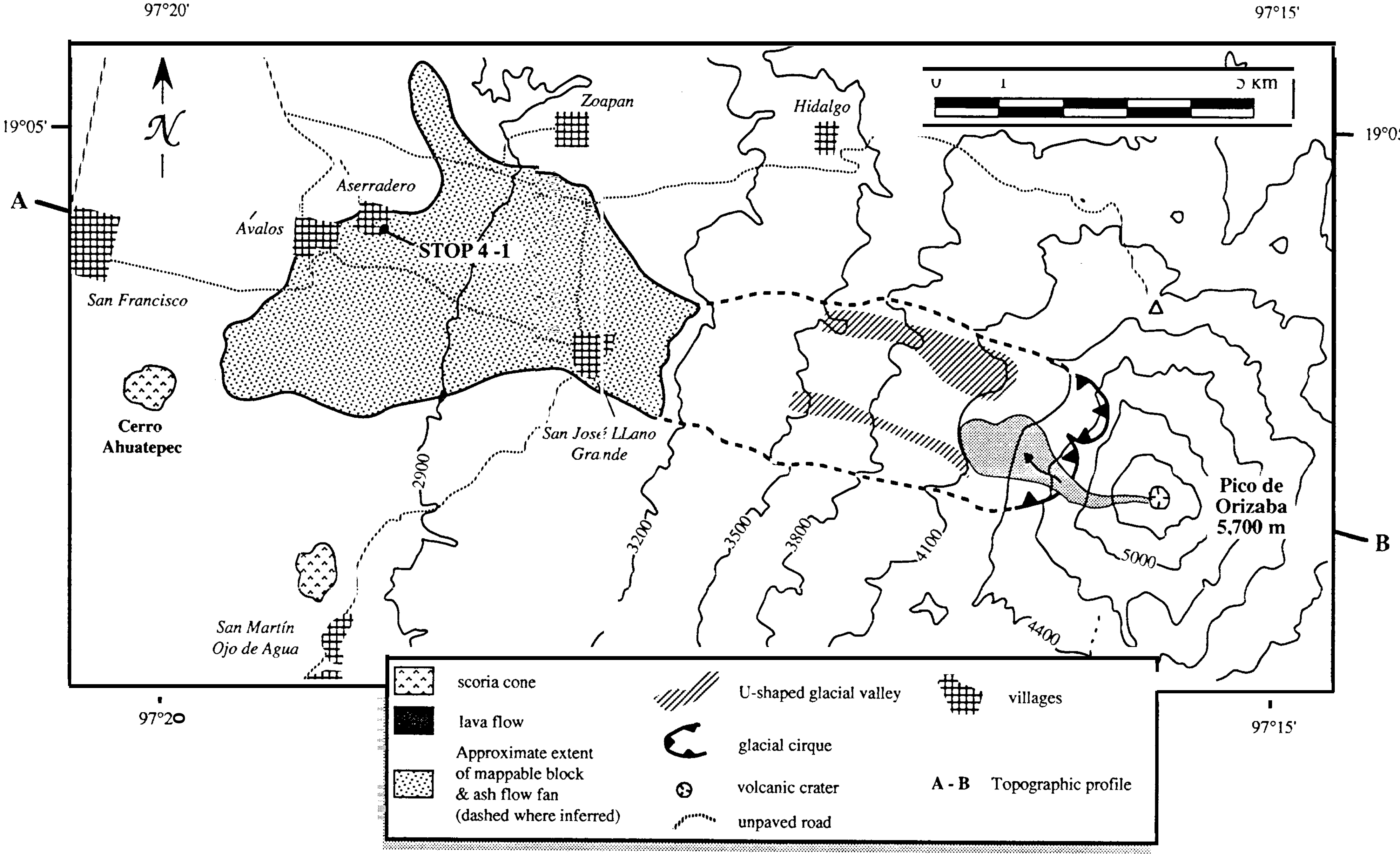
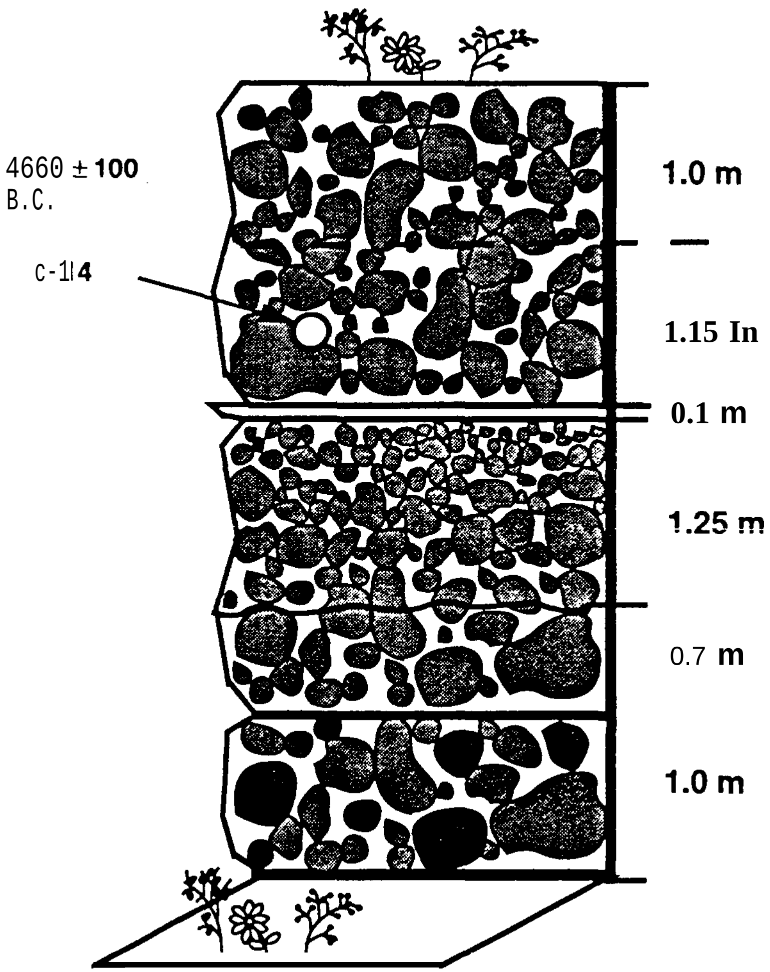

97°20'
97°15'
19°05'
19°05
A
B
N
0
1
5 km
Zoapan
Hidalgo
Aserradero
Ávalos
STOP 4 -1
San Francisco
Cerro
Ahuatepec
San José LLano
Grande
San Martín
Ojo de Agua
2900
3200
3500
3800
4100
4400
5000
Pico de
Orizaba
5,700 m
97°20
97°15'
scoria cone
lava flow
Approximate extent
of mappable block
& ash flow fan
(dashed where inferred)
U-shaped glacial valley
glacial cirque
volcanic crater
unpaved road
villages
A - B
Topographic profile

STOP 4-1



block-and- ash flow deposit, coarse and poorly-sorted, subangular boulders and gravel, mostly monolithologic (glassy porphyritic I-lbl-andesite), clast-suppported, few accidental clasts, roughly inversely graded, abundant charcoal at the base, sample 9004-B was taken from this horizon

surge-like deposit, rich in charcoal, blast ?

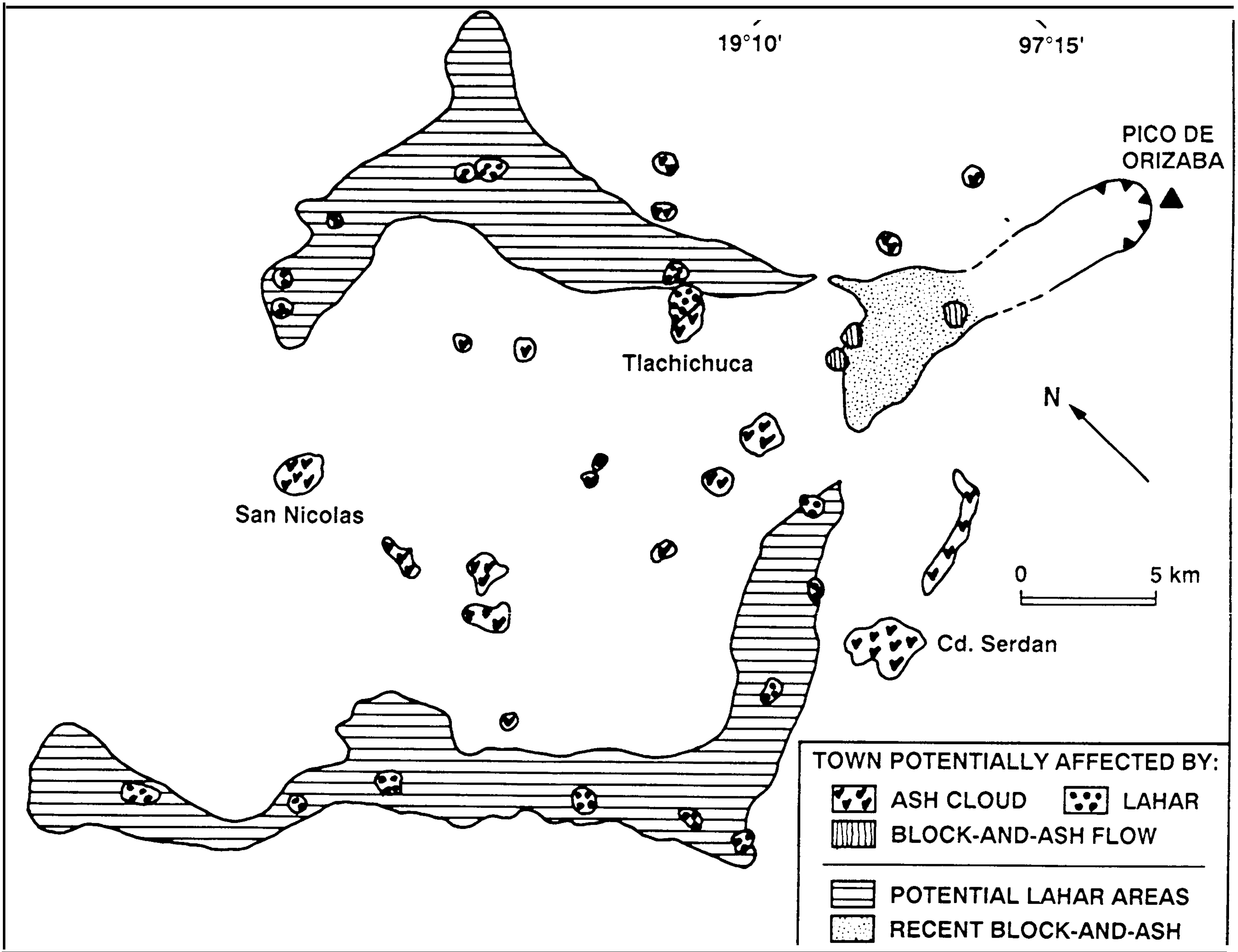
fluviatile-reworked deposit, coarse, clast-supported, sandy matrix, subrounded andesite fragments, normally-graded, erosive lower contact

fluviatile and laharic deposits, non-erosive lower contacts, normally graded, cut- and- fill structures, fine-grained upper layers, each layer 10-25 cm thick

block- and- ash flow deposit, subangular clasts, heterolithologic, unsorted, ungraded

present streambed of Barranca Piedra

PRELIMINARY VOLCANIC RISK MAP: WEST SLOPE PICO DE ORIZABA



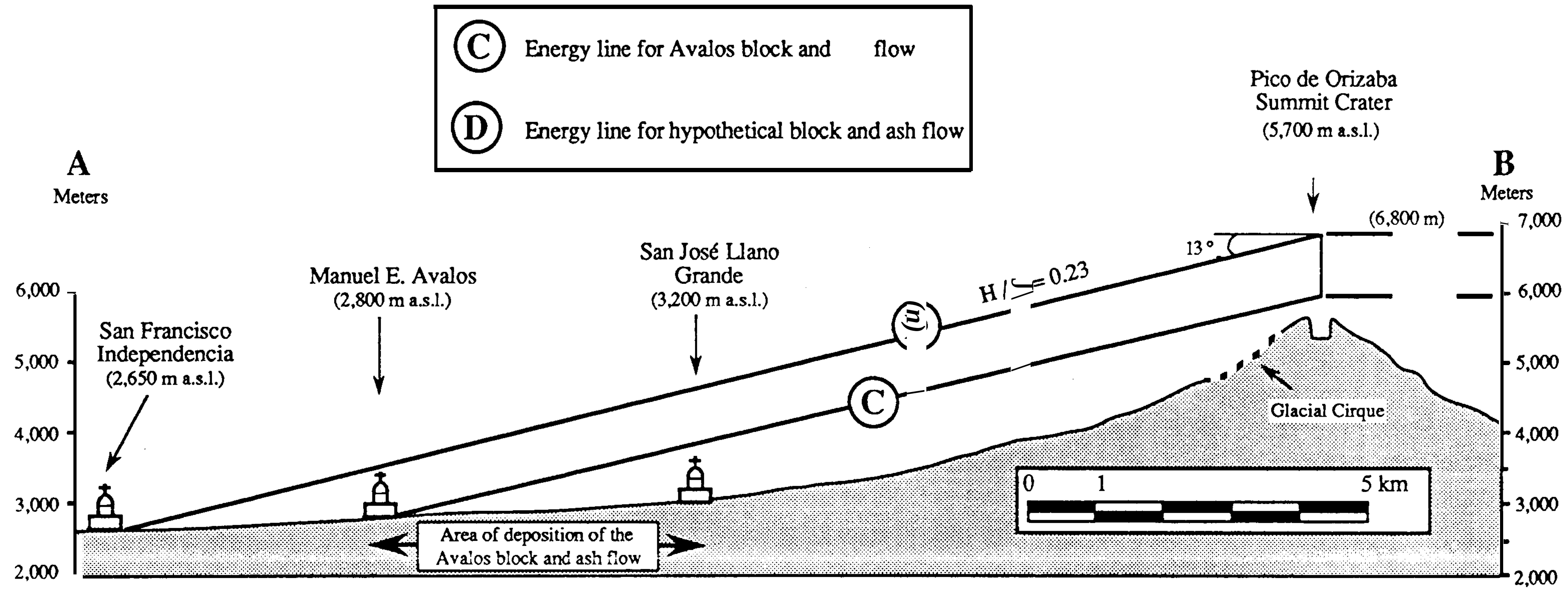


Fig 22. Siebe et al.

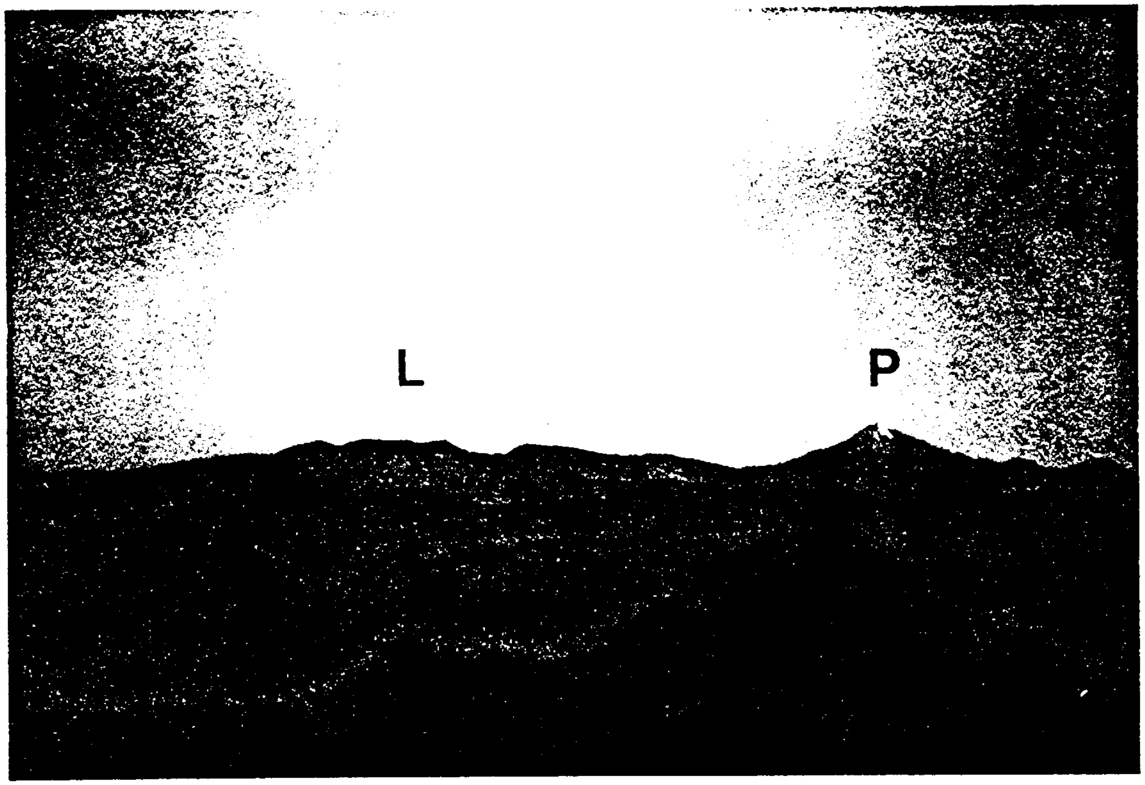


Fig. 22. Siew et al.

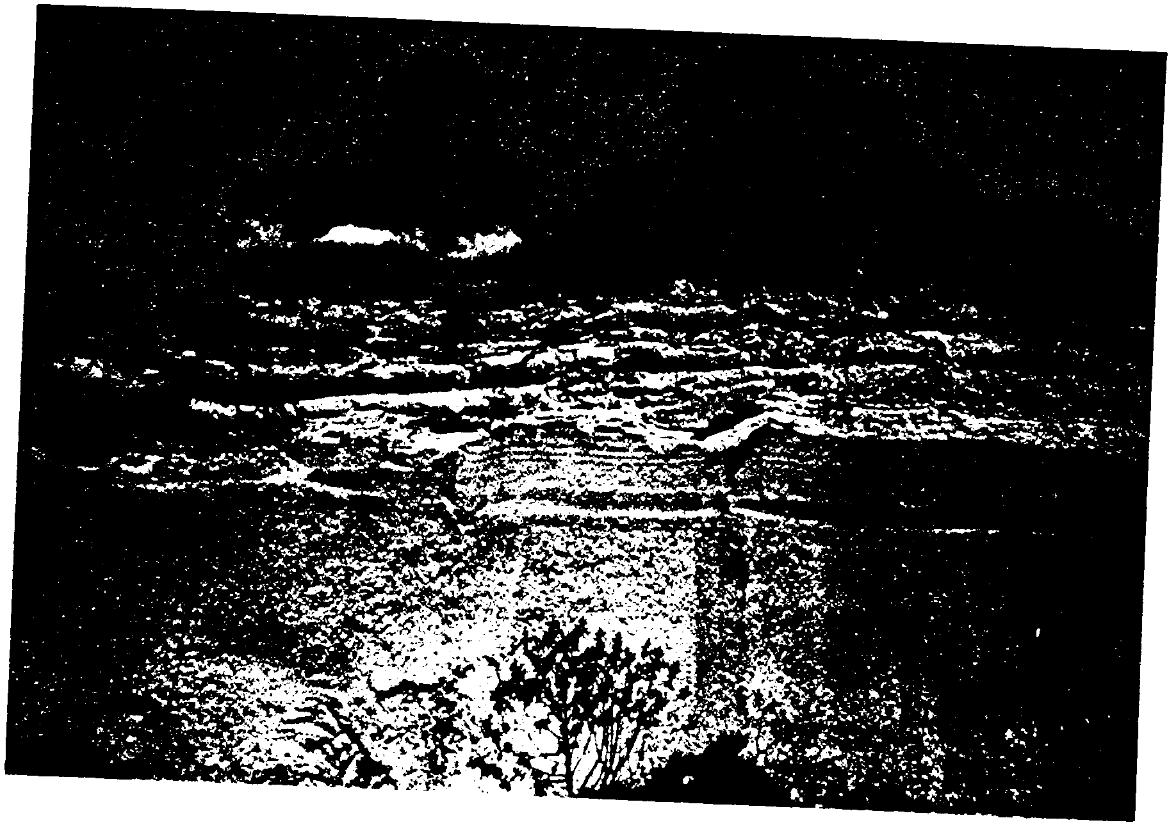
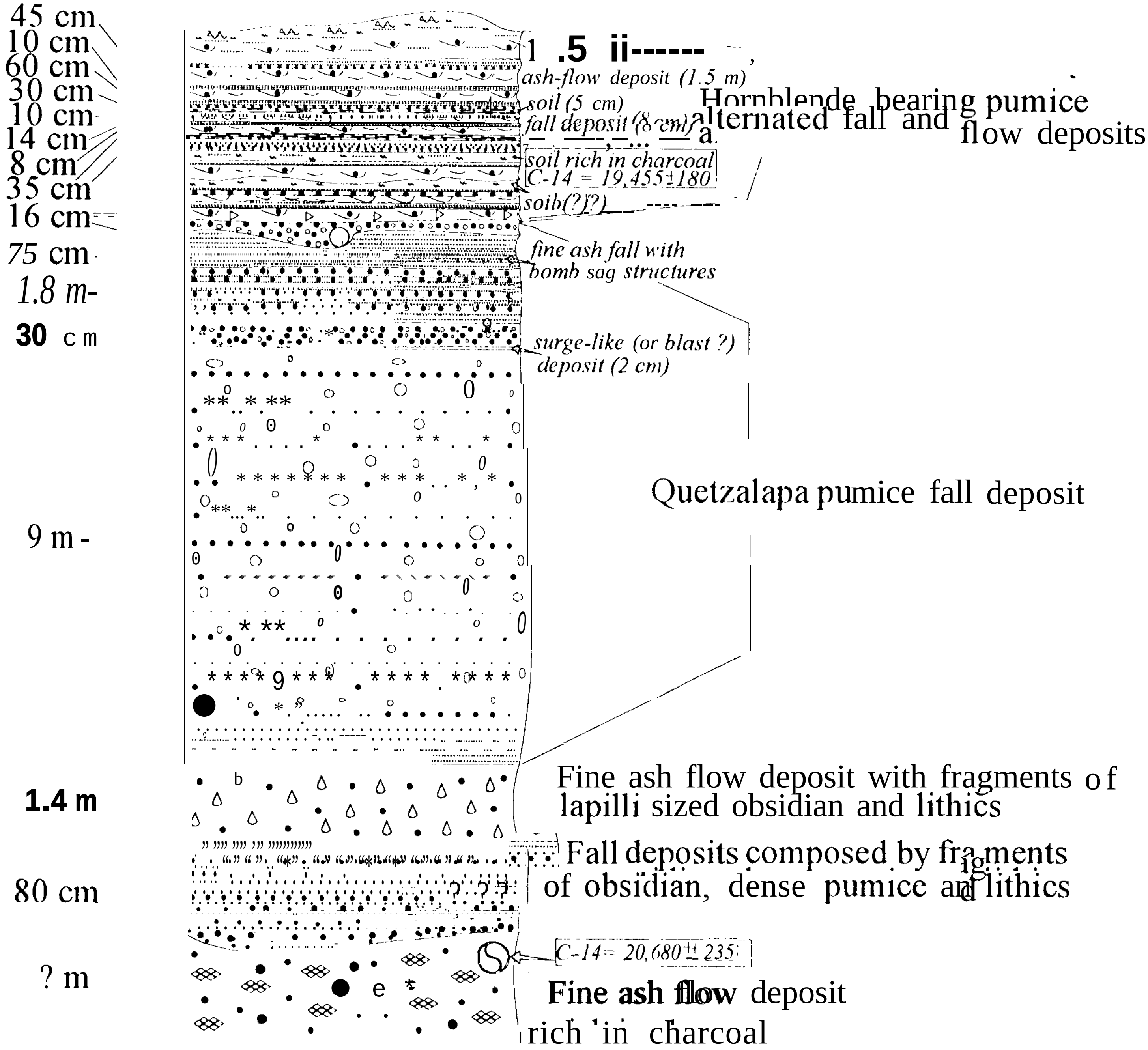
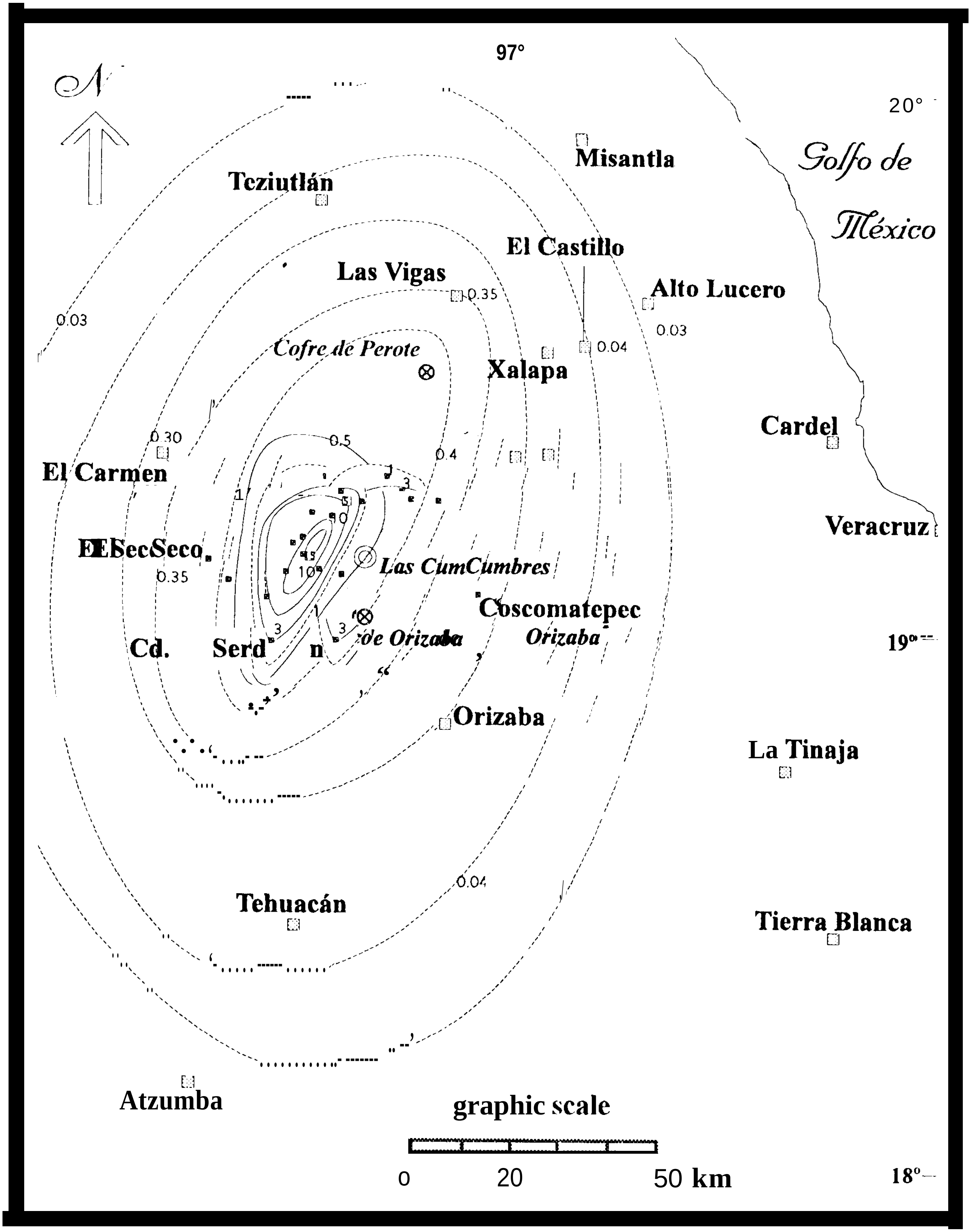


Fig. 24 Siele [illegible]



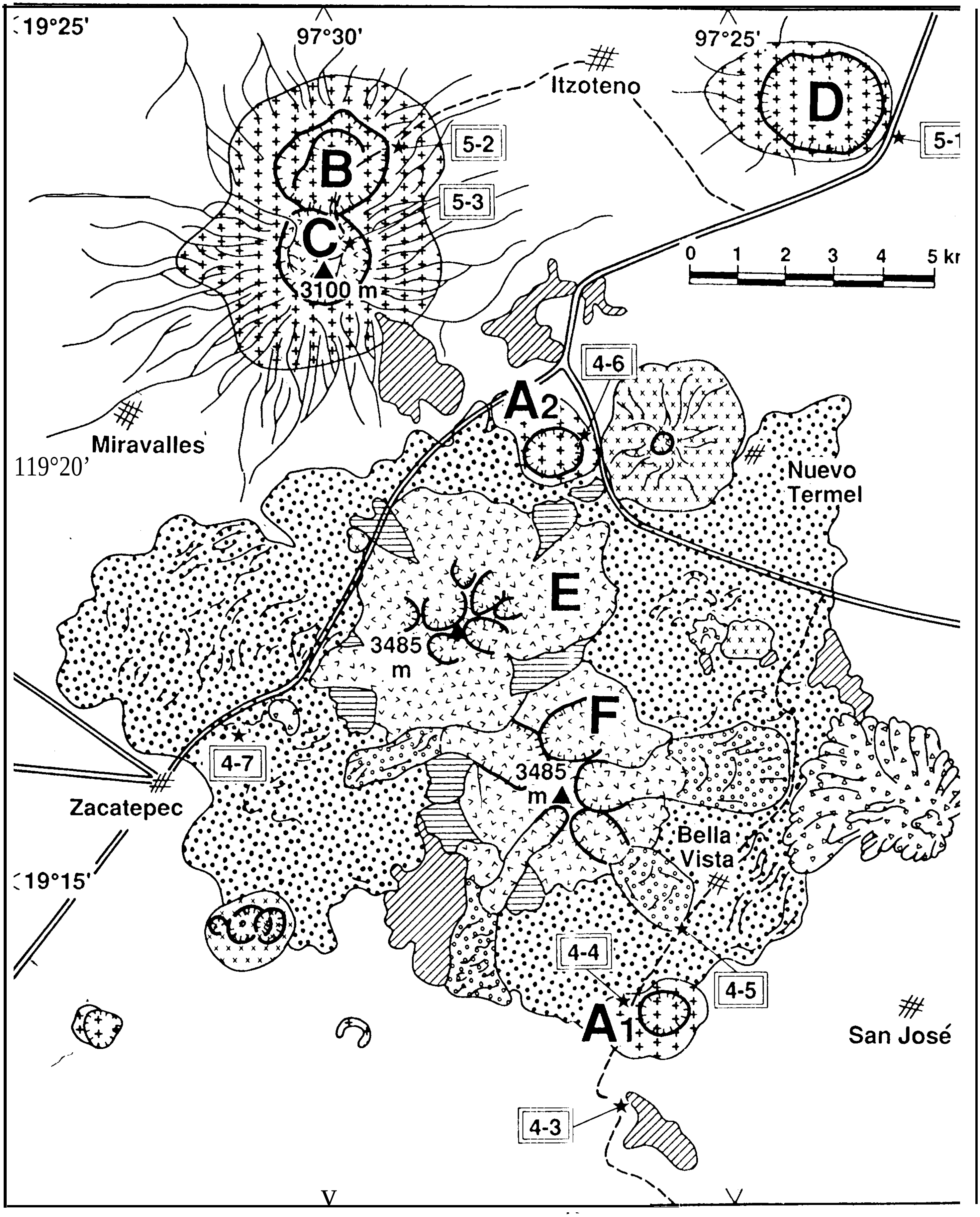
Stratigraphic column at Paso Nacional

Fig 25



Isopach map for the Plinian Quetzalapa pumice fall deposits

LAS DERRUMBADAS-CERRO PINTO RHYOLITE DOME COMPLEX



LEGEND

1-] Olivine basalt

[-] Andesite

Rhyolite

Las Derrumbadas talus deposits:
- Recent alluvial fan
- 2nd generation monolithologic debris avalanche deposit
- 1st generation heterolithologic debris avalanche deposit

Hydrovolcanic tuff

Cretaceus limestone and Tertiary monzonite

@ Debris avalanche scar

Crater

Arroyo

A Fumarole

A1 Tepexitl tuff ring

A2 Laguna Atexcac maar

B Cerro Pinto tuff cone

C Cerro Pinto dome

Flow front and ridges

\# Town

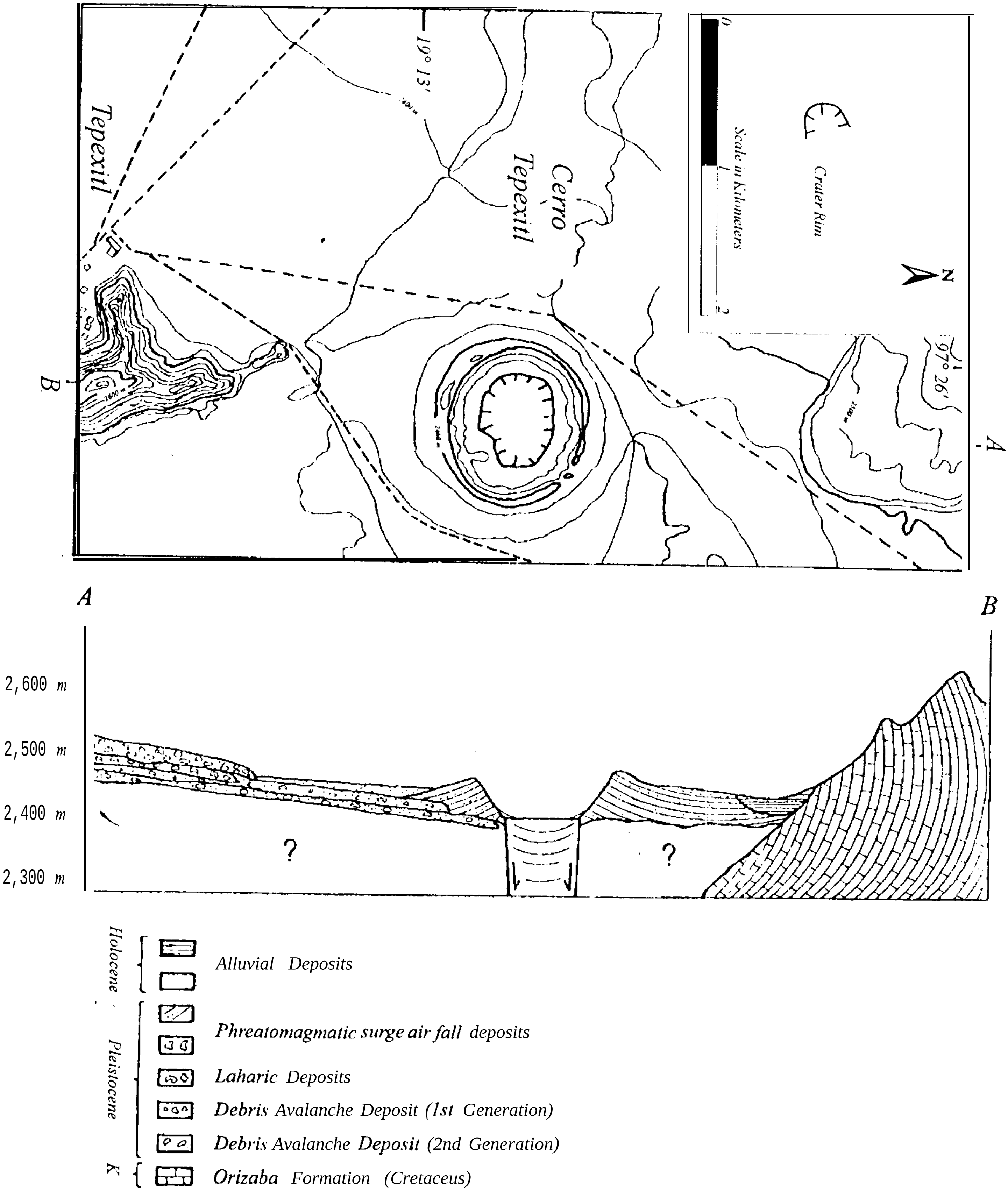
Paved, ---Dirt > Road

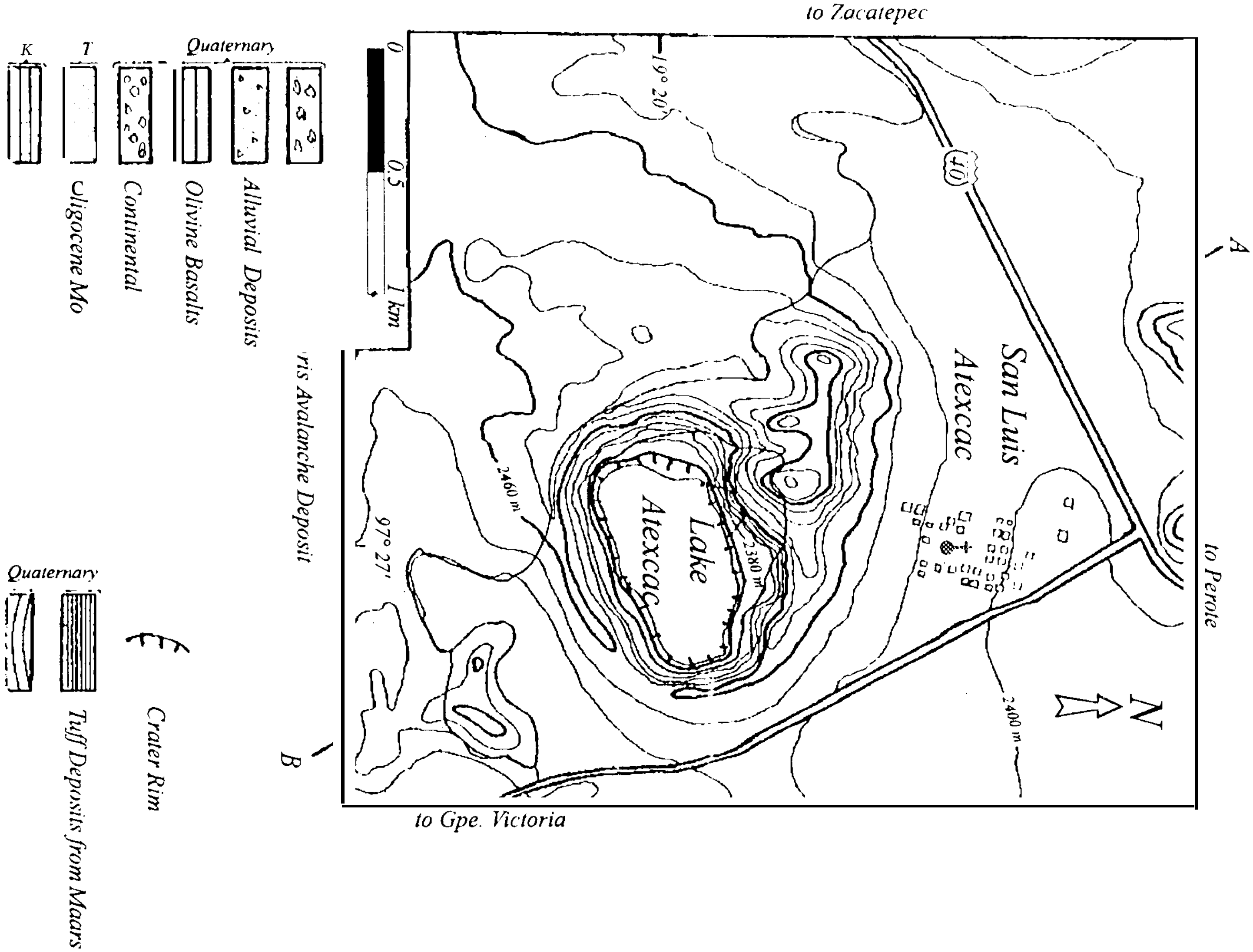
D Alchichica maar

E Las Derrumbadas NW dome

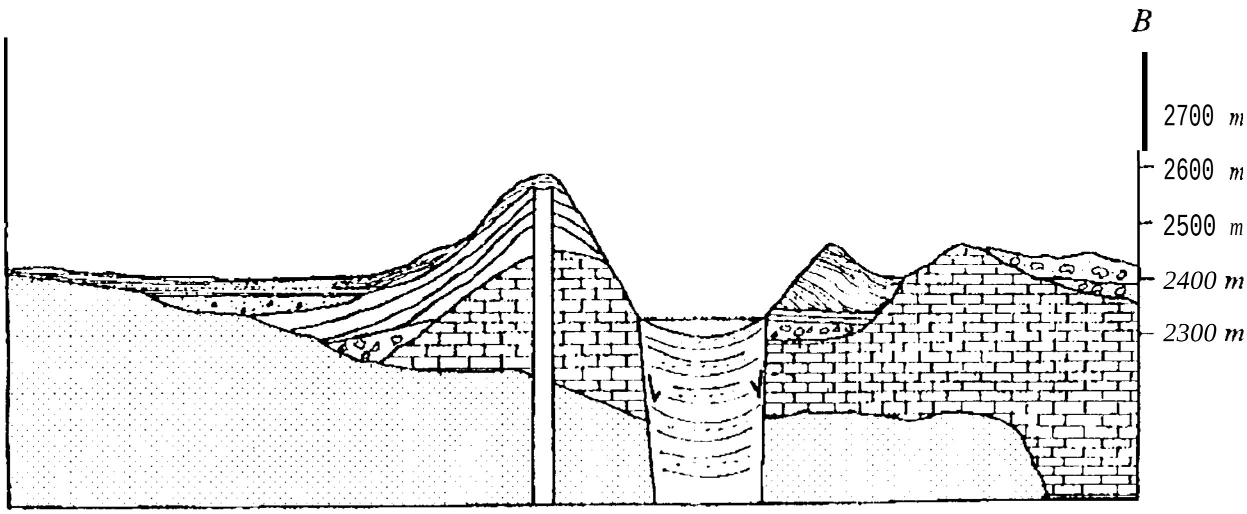
F Las Derrumbadas SE dome

5-2 ★ Field trip stop

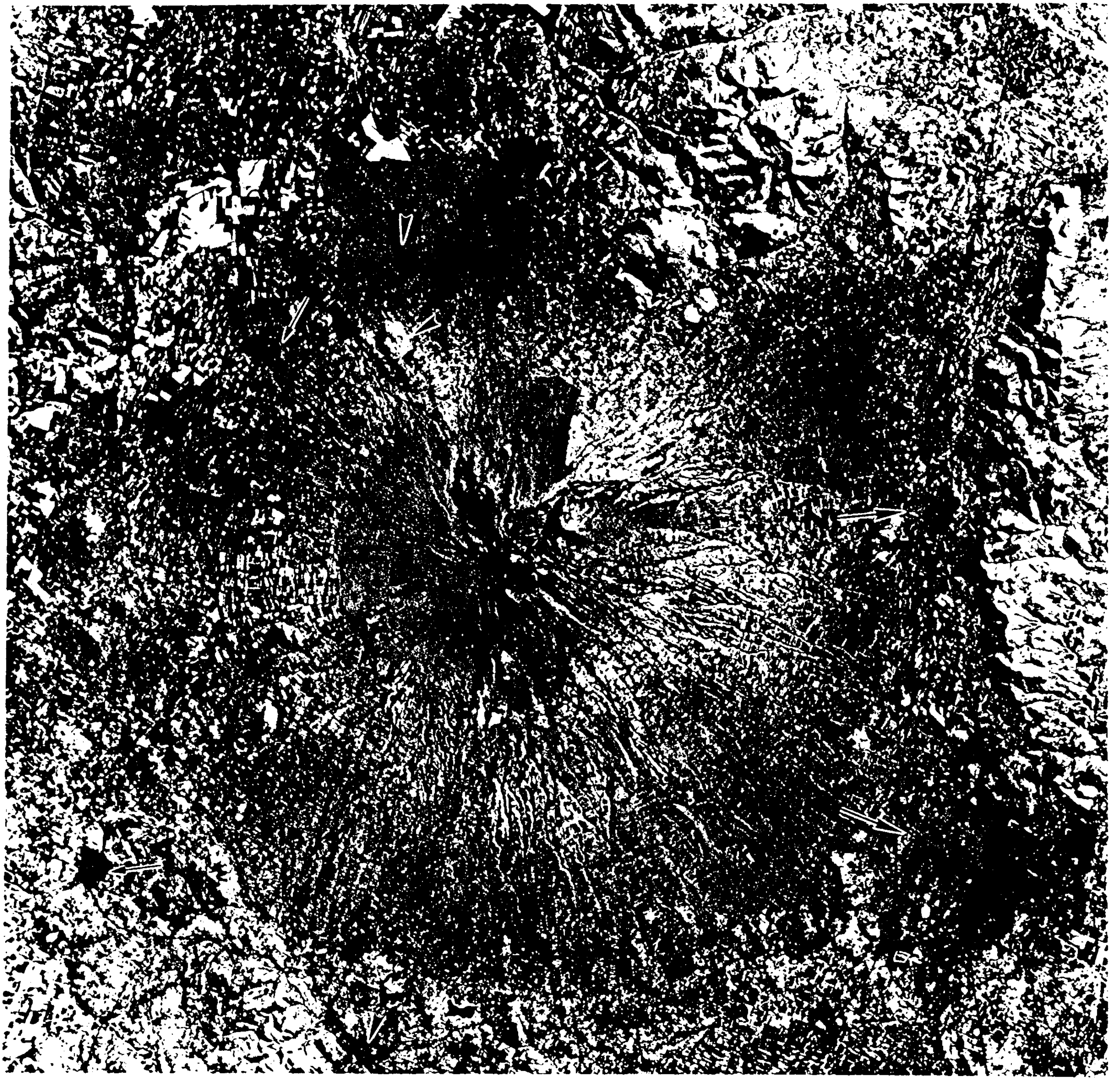

Tepexitl
19° 13'
Cerro Tepexitl
Scale in Kilometers
0
1
2
Crater Rim
N
97° 26'
A
B
A
B
2,600 m
2,500 m
2,400 m
2,300 m
?
?
Holocene
Alluvial Deposits
Pleistocene
Phreatomagmatic surge air fall deposits
Laharic Deposits
Debris Avalanche Deposit (1st Generation)
Debris Avalanche Deposit (2nd Generation)
K
Orizaba Formation (Cretaceus)

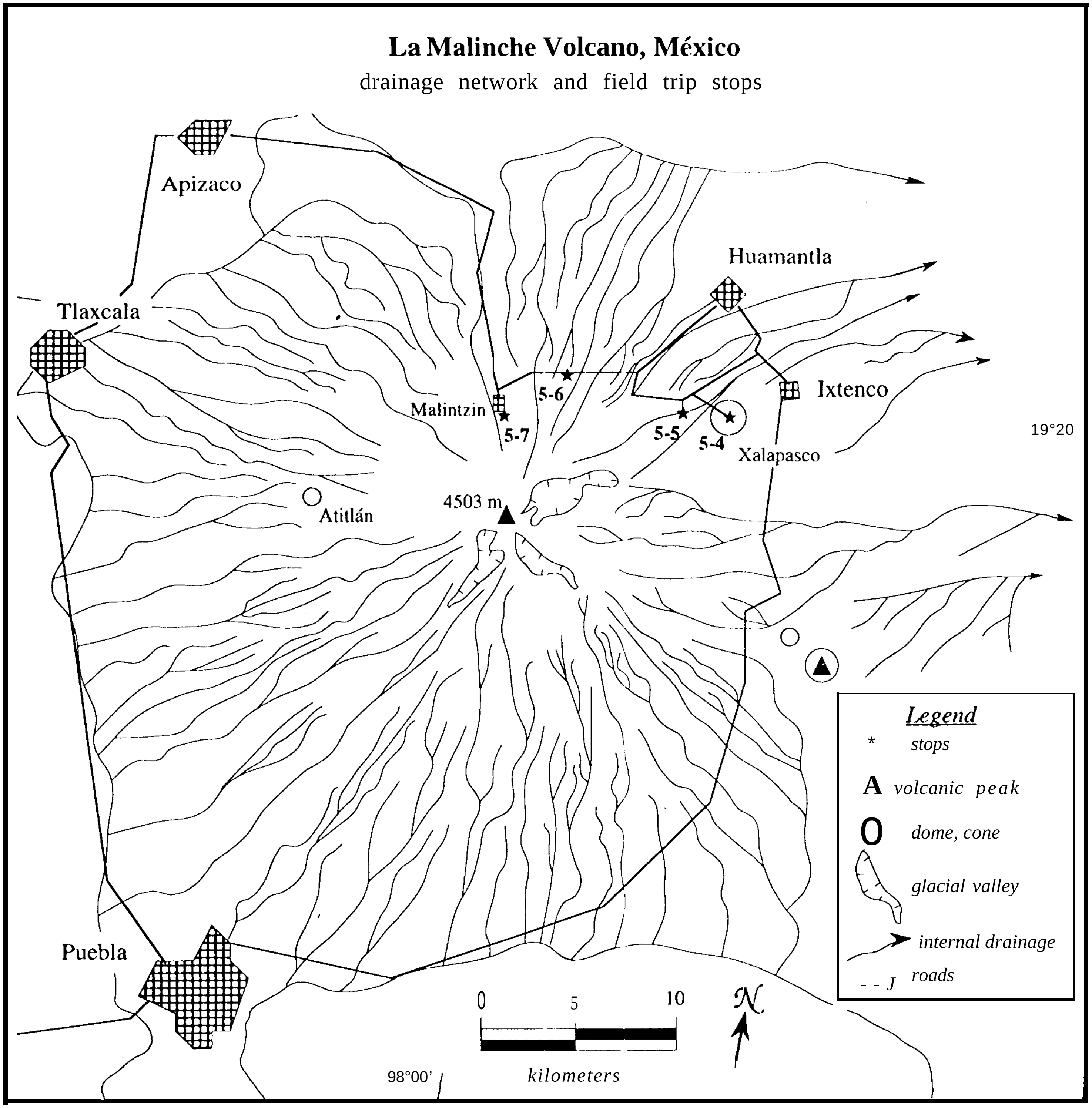


to Zacatepec
to Perote
to Gpe. Victoria
San Luis Atexcac
Lake Atexcac
40
19° 20'
97° 27'
2460 m
2380 m
2400 m
0
0.5
1 km
N
A
B
Quaternary
K
T
Alluvial Deposits
Olivine Basalts
Continental
Oligocene Mo
ris Avalanche Deposit
Quaternary
Crater Rim
Tuff Deposits from Maars



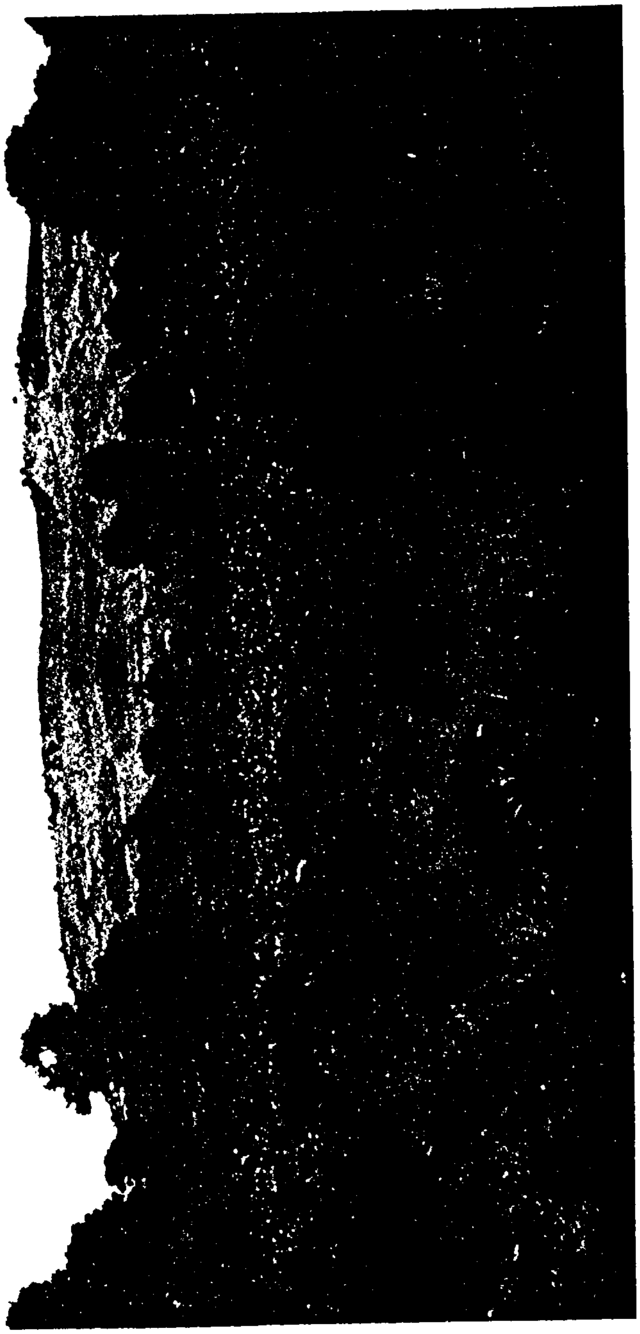
B
2700 m
2600 m
2500 m
2400 m
2300 m

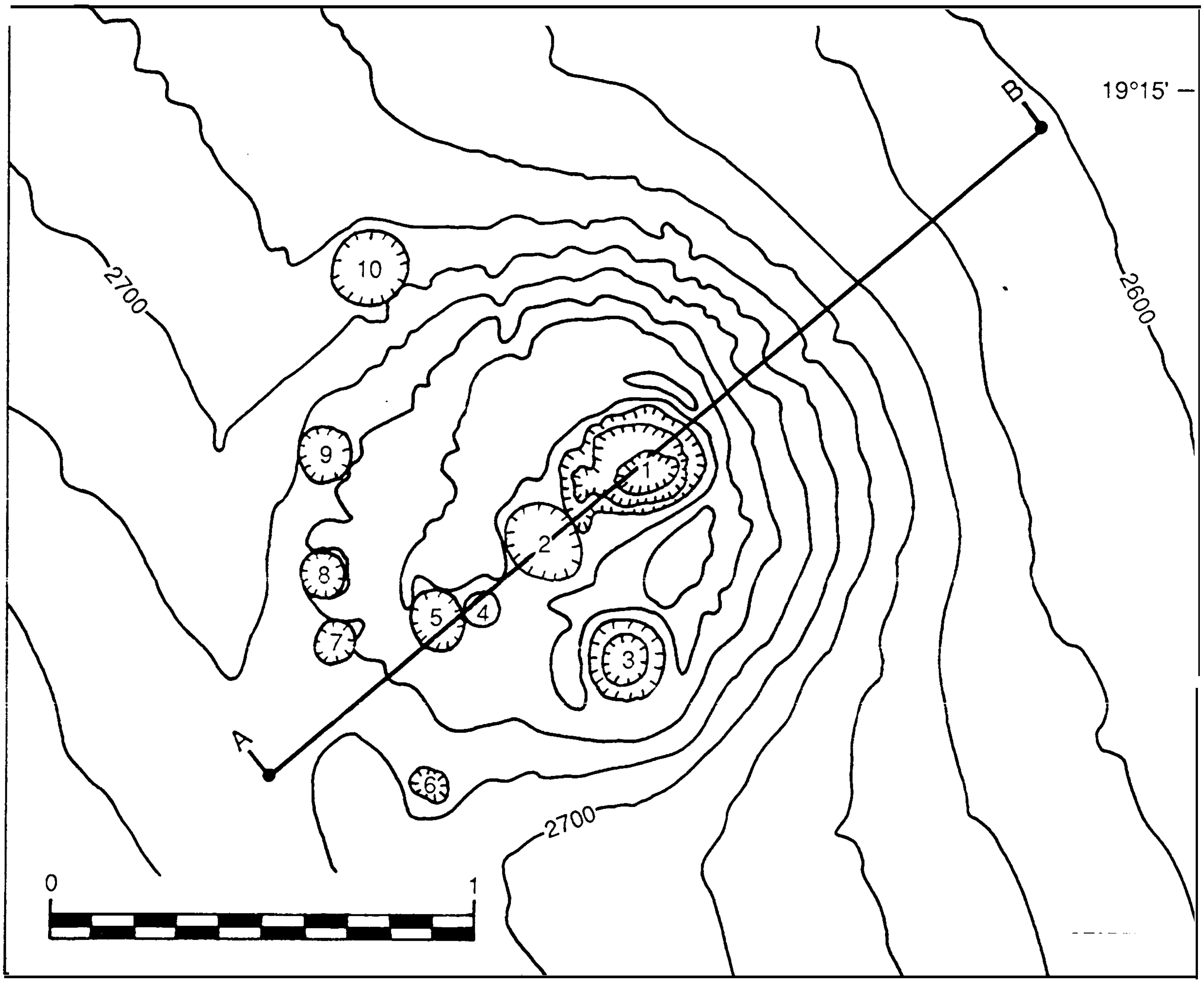




Adapted from Abrams and Siebe, 1994.

Fig. 3.




19°15'
B
A
2600
2700
2700
2700
1
2
3
4
5
6
7
8
9
10
0
1

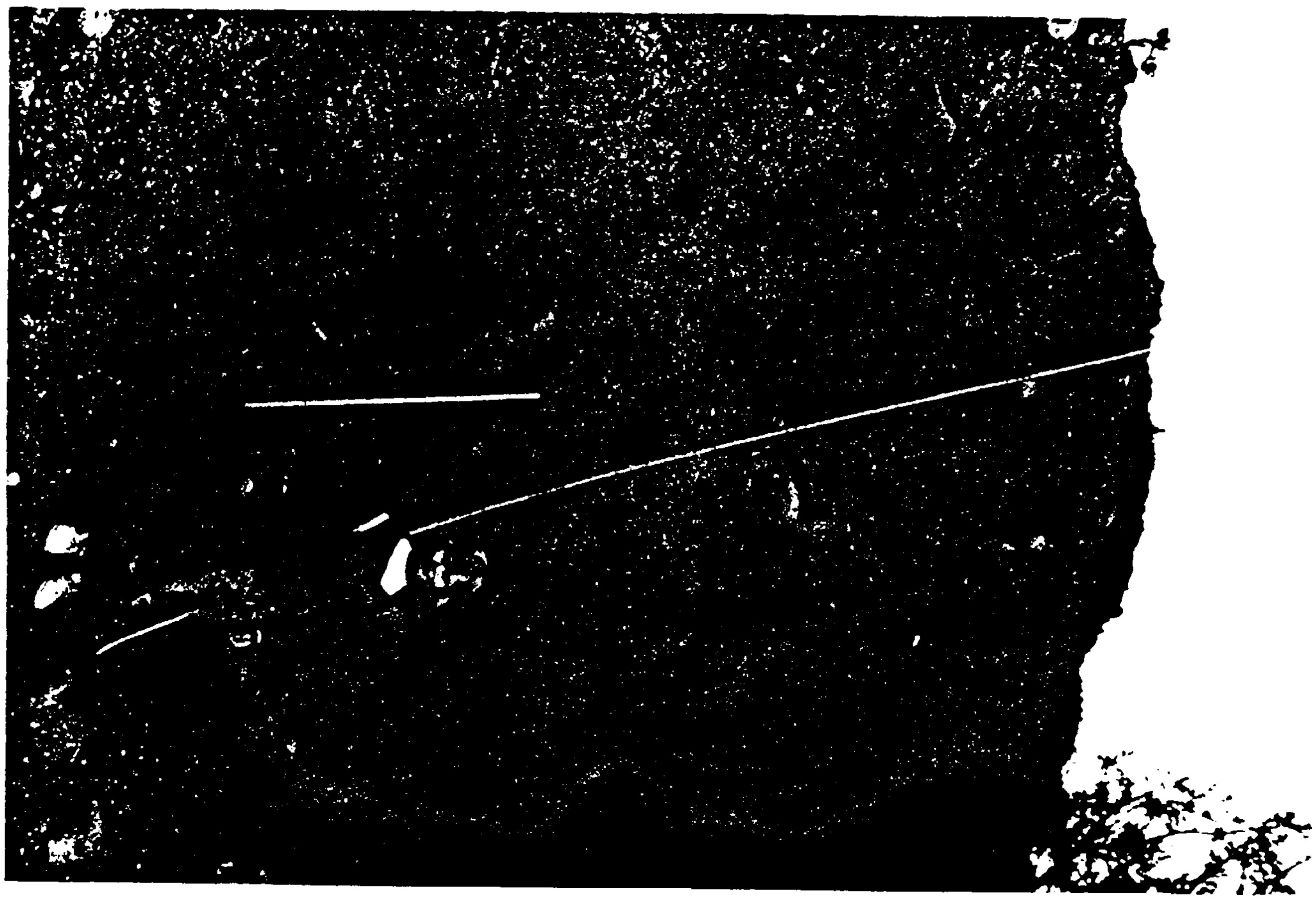


Fig. 36. [illegible]

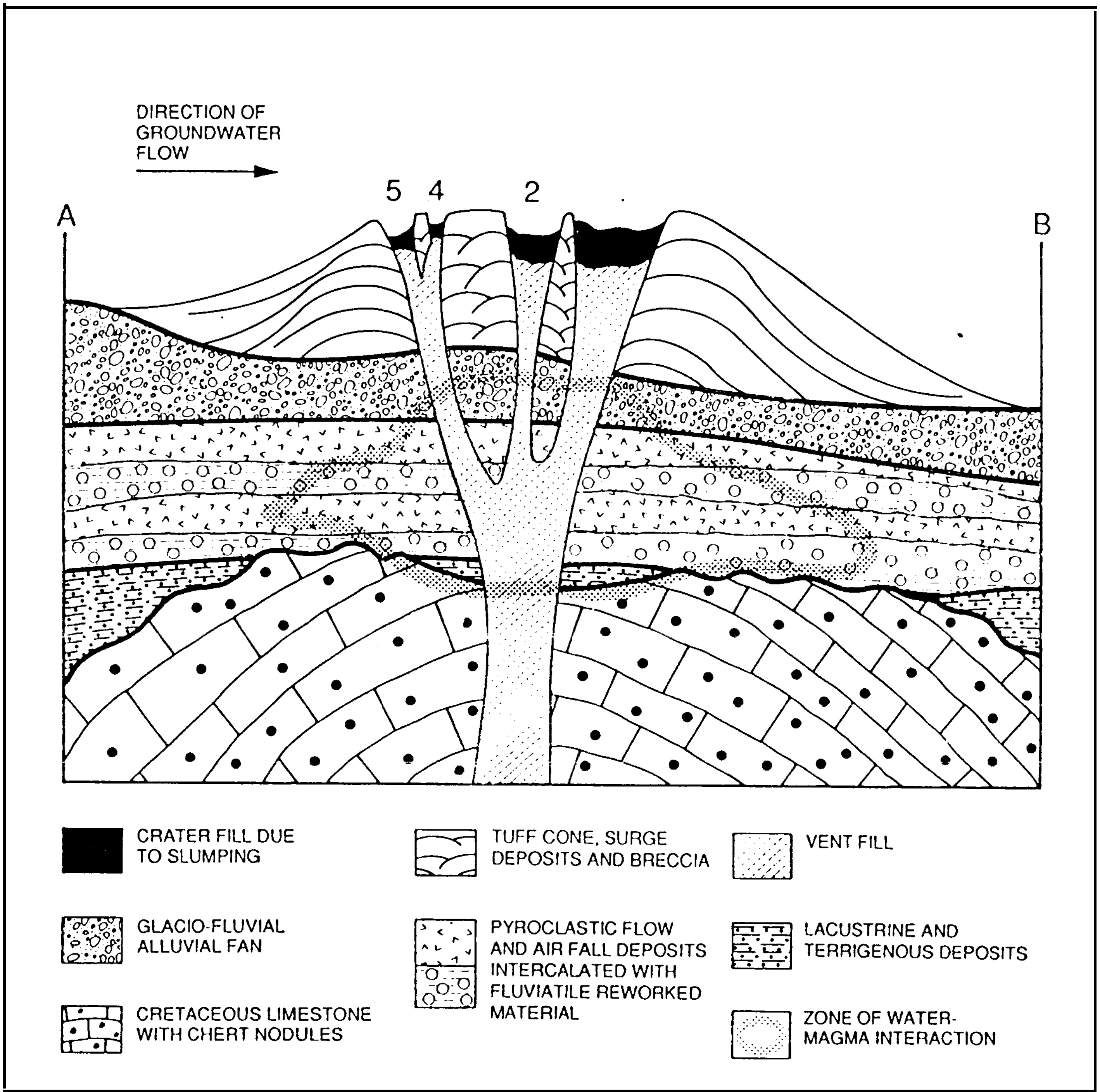
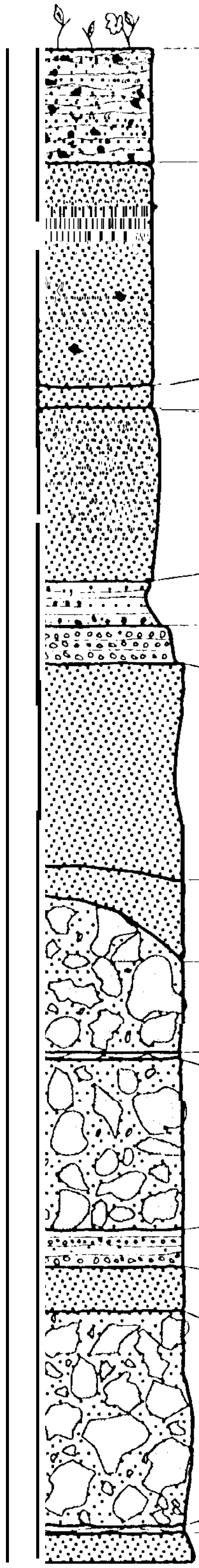

DIRECTION OF
GROUNDWATER
FLOW
5
4
2
A
B
CRATER FILL DUE
TO SLUMPING
GLACIO-FLUVIAL
ALLUVIAL FAN
CRETACEOUS LIMESTONE
WITH CHERT NODULES
TUFF CONE, SURGE
DEPOSITS AND BRECCIA
PYROCLASTIC FLOW
AND AIR FALL DEPOSITS
INTERCALATED WITH
FLUVIATILE REWORKED
MATERIAL
VENT FILL
LACUSTRINE AND
TERRIGENOUS DEPOSITS
ZONE OF WATER-
MAGMA INTERACTION

Fig. 27

stop 5-5

Alt. 2695 *m*

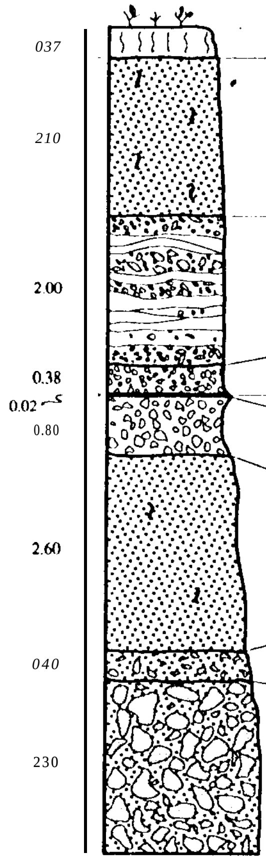


Thickness (m)	Description
1.50	*fluviatile reworked material.*
3.00	*ash-flow tuff.* Grey, indurated, non-welded, matrix supported, sand-sized.
0.30	*ash-flow deposit.* Grey, indurated, non-welded, sandy-gravelly.
2.30	*ash-flow tuff.* Beige, non-welded, matrix supported, silty-sandy.
0.60	*Plinian sand-and-gravel fall series.* Grey, angular andesite clasts.
0.50	*Plinian pumice-fall series.* White in color, rusty when weathered. Maximum pumice diameter = 5 cm. Normally graded
2.70	*ash-flow tuff.* Yellowish beige, non-welded, matrix supported, silty-sandy.
0.40	*ash-flow deposit.* Grey, friable, matrix supported, sand and gravel.
2.10	*block-and-ash flow deposit.* Clast supported, consists of porphyritic andesite/dacite clasts reddish grey in color. Clasts are angular to subrounded.
0.10	*surge deposits.* Sandy-gravelly, grey in color.
2.30	*block-and-ash flow deposit.* Clast supported, consists of porphyritic andesite/dacite clasts reddish grey in color. Clasts are angular to subrounded.
0.50	*Plinian fall secuence.* Intercalated layers of white pumice and grey sandy ash.
0.60	*ash-flow tuff.* Yellowish beige, non-welded, matrix supported, silty-sandy.
2.90	*block-and-ash flow deposit.* Clast supported, consists of porphyritic andesite/dacite clasts reddish grey in color. Clasts are angular to subrounded. Maximum clast diameter = 1 m.
0.07	*surge deposits.* Grey, silty-sandy with cross bedding.
> 0.44	*ash-flow tuff.* Light brown, friable, non-welded, matrix supported, sand-sized with very small pumice fragments. Maximum pumice diameter = 3 cm.

thickness in m

Stop 5-6

Lat. 19 °16’55”
Long. 98° 00' 23"
Alt. 2995 *m*



soil. Brown silty.

ash-flow tuff. Brown, non-welded, silty-sandy with lithics and rare pumice, matrix supported. Rich in charcoal. Maximum lithic diameter = 1.0 cm. Maximum pumice diameter = 2.5 cm.

surge secuence. Secuence of sand and gravel layers containing grey clasts of porphyritic dacite. Clasts are angular to rounded. Maximum clast diameter = 12 cm. Secuence shows cross bedding.

Plinian pumice fall. Angular to subrounded white pumice. Maximum pumice diameter = 7 cm. Pumice contains biotite.

Plinian ash fall. Fine grey sandy-silty ash.

Plinian pumice fall. Angular to subrounded white pumice. Maximum pumice diameter = 13 cm.

ash-flow tuff. Brown, non-welded, matrix supported, with disseminated charcoal.

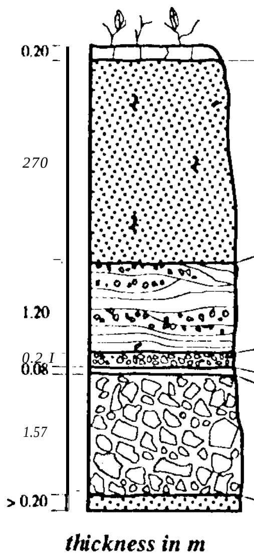
ash-flow deposit. Angular to subrounded grey andesite, cobble to sand-sized.

block-and-ash flow. Angular to subrounded, pinkish grey clasts of porphyritic dacite. Maximum clast diameter = 30 cm.

thickness in m

stop *5-7*

Lat. 19°16'41"
Long. *98°01'31"*
Ah. *3 100 m*



soil. Brown, silty.

ash-flow tuff. Brown, non-welded, matrix supported, consists of sandy silt containing disseminated charcoal.

surge secuence. Intercalated layers of sandy silt and sandy gravel showing cross bedding. Clasts are angular to subrounded and they are of porphyritic andesite/dacite grey and pink in color.

Plinian pumice fall. Angular to subrounded white pumice. Maximum pumice diameter = 7 cm.

Plinian ash fall. Massive, non-welded, consists of sandy ash.

Plinian pumice fall. Angular to subangular white pumice containing lithic clasts. Core pumice is pinkish red in color. Maximum pumice diameter = 48 cm. Maximum lithic diameter = 60 cm.

ash-flow deposit. Grey, non-welded, consists of sandy ash.